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ECTRICAL EQUIPMENT

A PRACTICAL TREATISE ON THE OPERATION AND MAINTENANCE OF RAILWAY DIESEL LOCOMOTIVES

by JOHN DRANEY

PAST PRESIDENT, UNITED ASSOCIATIONS OF RAILROAD VETERANS

ILLUSTRATED

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ERICAN TECHNICAL SOCIETY, PUBLISHERS

:AGO, U.S.A.

Reprinted, 1944

This book is produced in conformity with government regulations for saving paper. It is complete and unabridged in contents.

Printed in the U.S.A.

PREFACE

MANY steps in advance have been taken in Diesel Engineering since the day, toward the end of the nineteenth century, when Rudolf Diesel proposed to compress pure air only in the cylinders an internal-combustion engine, and to inject the fuel—in this case, rst, crude oil—when the end of the compression stroke was reached.

That proposal was indeed a stroke of genius, and like many ther in the world of discovery and invention, it passed unnoticed a while in the field of American transportation. The gasoline gine was being developed as motive power for the automobile; and nsportation heads were filled, like those of the public, with the sibilities or threats of the gas-powered motor-car. Hence the Diesel ine had to wait, and it is only in recent years that it began to ne into its own as an improved form of motive power for railway nsportation.

Today Diesel-electric locomotives are in service on many railroads this and other countries, and their development and use are gressing at a rapid rate. Ever since the Diesel was first designed heavy duty, the recognition of its value and reliability for the poses of industry and transportation has been increasing; and with demand for Diesel engines has grown the parallel demand for n willing to learn how to operate, service, and maintain them.

Many such men are in railway and industrial employ, watching h interest the steady advance of Diesel engineering and Diesel ac- nplishments. For such men, and all other young and ambitious n of a practical turn of mind, the Railway Educational Department the American Technical Society has prepared this and other umes of instructive text, dealing with the subject of Diesel Engi- ring and allied topics. This volume on Electrical Diesel and another ume on Mechanical Diesel should go far toward giving the earnest dent an exact and expert knowledge of this modern and important nch of engineering.

This text deals in the utmost detail with the electrical equipment the Diesel engine, with particular reference to its adaptation and in railway transportation. The text is the well-considered work of

eminently practical and competent authors, the following men having collaborated in its preparation and constituting its authority:

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Thus, with this invaluable aid and cooperation, we have succe in producing for students of Diesel Engineering a most practical reliable source of information and instruction, for the special be and use of railway employes and others who may be, or who d to be, concerned with the construction, operation, servicing, general maintenance of Diesel motive power in railway service.

The authors and collaborators wish to acknowledge the inest ble value and cooperation of the Editorial Advisory Board listed, have cooperated and helped in making this work a success.

They also wish to acknowledge the use of the technical mate and illustrations contributed by all companies, particularly the Am can Locomotive Company, Baldwin Locomotive Works, Elect Motive Division of General Motors, General Electric Company, the Westinghouse Electric & Manufacturing Company.

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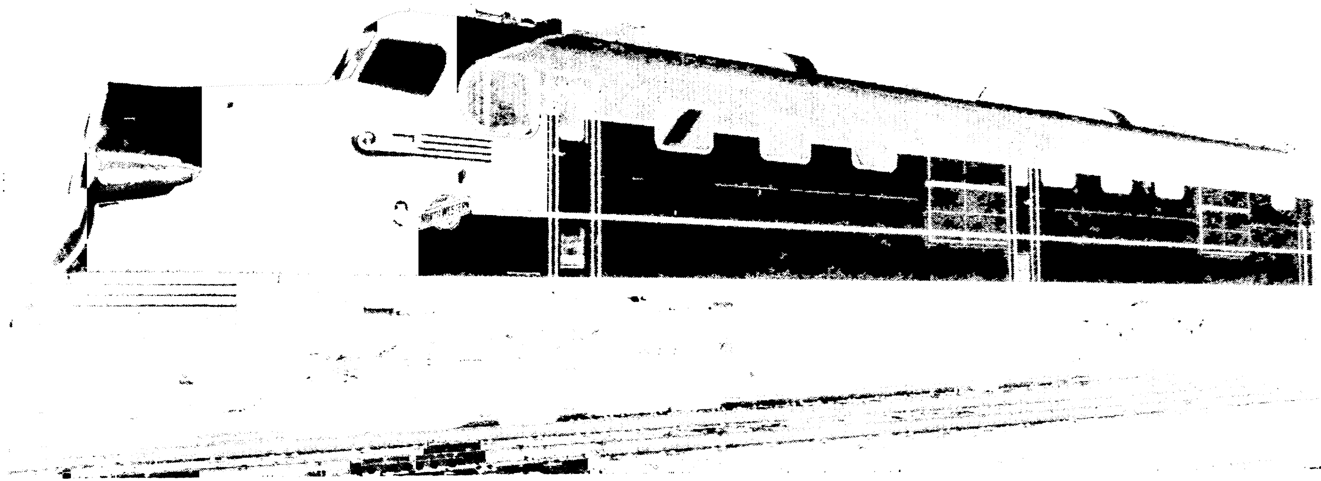


Chicago and North Western Diesel Locomotive
Courtesy of American Locomotive Company

Chapter I

Current Electricity

What is Electricity? This is a question that is often asked but it is usually never satisfactorily answered. The reason for this is because electricity cannot be seen, heard, or handled like other objects. This makes it impossible to learn about electricity as you learn about other objects. Undoubtedly the simplest definition to the question is: "Electricity is a form of energy."

What is energy? When the sun shines bright, it is warmer than on a cloudy day. This invisible "something" in the sunlight is energy. When the sunlight strikes the earth, this energy is turned into heat that warms the ground. On cloudy days there is not as much of this energy striking the earth, and the day is usually cooler than when the sun is shining brightly.

This energy from the sun, when it is turned into heat, causes the grass and trees to grow. When trees are cut down and burned in a boiler, the energy from the wood is turned into heat. The heat from the flames turns the water in the boiler into steam. Steam is another form of energy.

A steam engine or steam turbine will change this energy from the steam into mechanical energy. Mechanical energy can be used to run any machine connected by the use of belts and pulleys to the steam engine or turbine. An electric generator can be connected to a steam engine or turbine, and the mechanical energy produced by these machines is turned into another form of energy which is known as electrical energy, or electricity. Therefore, electricity is a form of energy.

ELECTRIC CURRENT

When it rains what becomes of the water that falls on the roof of the house? It runs off the roof on to the eaves, then into the trough or gutter, and from there through a connected pipe down

the side of the building. The trough, and the connected pipe direct the flow of water to the desired place.

To direct the flow of electricity to the desired place, a copper wire is usually used. This flow of electricity, which is called electric current, flows through the copper wire just like water flows through the pipe down the side of the building. Electricity, however, is not a liquid, even though practical electricians often refer to it as "the juice" and in closing a switch they will speak of "turning on the juice." However, in order to understand the flow of electric current, which cannot be seen, it must be compared with something that can be seen or understood, and for this reason the flow of water will be used to illustrate the flow of electric current.

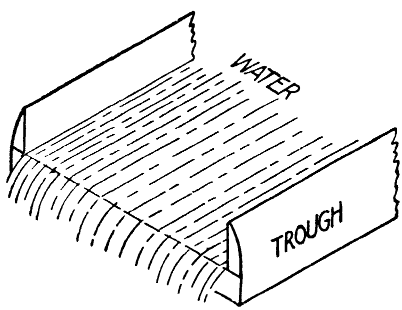


Fig. 1. Trough Used to Determine Rate of Flow of Water

AMPERES

What becomes of the water on top of the hill when it rains? It runs down the hill into a ditch. Ditches are not the same size. Some ditches are small and some are very large. Some ditches have very little water in them, and some are nearly full. This statement gives us some idea as to the amount of water flowing in the different streams. It is not very accurate, however, because a large ditch may have only a small amount of water in it, while a small ditch may be nearly full. In order to measure the flow of water in a ditch or stream, an engineer would use an arrangement like the one shown in Fig. 1. The rate of flow of water would be expressed as so many gallons per minute or cubic feet per second.

The same condition is true in regard to electricity. It is necessary, however, to have some word to express the **rate of flow of electric current.** This word is **ampere** (pronounced am-peer). When speaking in terms of electricity we say that the rate of flow of current is so many amperes, as, for example, 1 ampere, 2 amperes, 5 amperes, 10 amperes, 100 amperes, or 1000 amperes, as the case may be. If there are 5 amperes flowing in one wire and 10 amperes flowing in another wire, there is twice as much current flowing through the second wire as the first. Therefore, whenever you see the word **ampere,** it means the rate of flow of current, which is similar to the water flowing in a trough shown in Fig. 1.

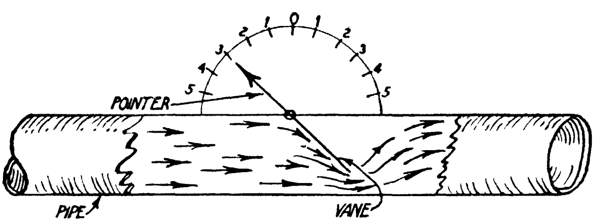


Fig. 2. A Device Which Shows the Rate of Flow of Water through a Pipe

AMMETER

In order to measure the rate of flow of water through a pipe, it is necessary to place something in the pipe that will indicate this rate of flow. This can be done with the device shown in Fig. 2, which could be called a flowmeter. This device consists of a sheet of iron, called a vane, which is placed inside the pipe and hinged to the top of the pipe. The vane is of such size that it will completely close the opening in the pipe. A pointer on the outside of the pipe is fastened to the vane to show its position in the pipe. A spring (not shown) will cause the vane to close the opening in the pipe when there is no water flowing through the pipe. The pointer will then point to zero. Therefore, the greater the amount of water that flows through the pipe, the greater will be the swing of the vane, as shown in Fig. 2, and the pointer will move accordingly opposite a larger number on the dial of the flowmeter.

The device used to measure the rate of flow of electric current was at first called an ampere-meter, because it showed the rate of

flow of electric current in amperes. As this name, ampere-meter, was rather long, it was shortened to ammeter. A view of an ammeter is shown in Fig. 3. An ammeter is always connected so the current will flow into the meter at one terminal, then through the meter, and out of the meter at the other terminal.

PRESSURE

When it rains, the water runs off the side of a hill and into a ditch, because water always runs down hill. But why does water always run down hill? Because water has weight, and the weight of the water above tends to push the water that is below out of its way. This weight of water above, tending to squeeze or push the water below, produces a pressure. And the greater the height of

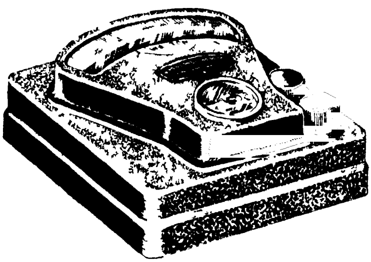


Fig. 3. Outside View of Ammeter

the water above a point, the greater is the pressure. This you have undoubtedly noticed if you have ever tried to stop the flow of water from a pipe connected to a high tank or from a water faucet by placing your hand over the end of the pipe or faucet. You remember that the water squirted out around your hand, and the pressure was very strong, much stronger than from the bottom of a tank. This shows that it is the pressure which forces the water through the pipe of a water system or pipe line. It is this pressure which forces the water from the pumping station into an overhead tank and carries it through the underground pipes to the faucets in our homes.

ELECTRICAL PRESSURE

Electric current flows through a wire or conductor on the same principle that water flows through a pipe. We have found that it

is **pressure** that causes water to flow through a pipe. Therefore, it is **pressure** that causes electric current to flow through a wire or conductor—except that with the electric current it is an **electrical pressure.** Where does this electrical pressure come from? It comes from dry cells, wet cells, storage batteries, and electrical generators.

VOLT

The electrical pressure produced by a dry cell, a storage battery, or an electric generator is not always the same. An electrical generator can be designed and built to produce almost any desired

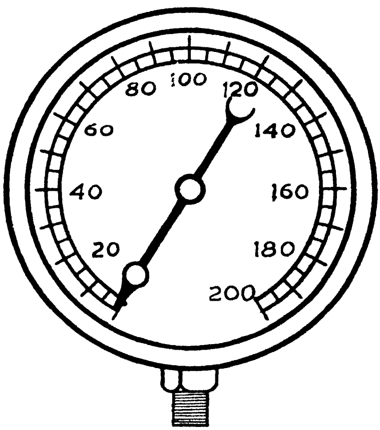


Fig. 4. Steam or Water Pressure Gauge

pressure. The word used to express electrical pressure is **volt.** The electrical pressure of a dry cell is 1½ volts; that of an automobile storage battery is about 6 volts; that of the electric current used to furnish light in our homes is about 110 to 120 volts; the electrical pressure of the big transmission or power lines run through the country from one city to another is 33,000 volts, 66,000 volts, or 132,000 volts.

VOLTMETER

A pressure gauge is placed on every steam boiler in order to know the pressure inside of the boiler. This gauge enables the fireman to know whether he has enough fire in the boiler to produce the necessary pressure of steam. At the waterworks, or pumping

station, a pressure gauge like the one shown in Fig. 4, is connected to the pipe line, in order that the person operating the pump can tell whether there is sufficient pressure to force the water through the pipe. Every automobile owner has a little pressure gauge which he uses to test the pressure of air in the automobile tires.

Electrical pressure, which forces an electric current through a wire, is determined by a device which is called a **voltmeter,** Fig. 5. This device is called a voltmeter because it shows the electrical pressure in volts. You will notice that the outside view of the voltmeter shown in Fig. 5 is very similar to the ammeter shown in Fig. 3. In fact, the manufacturers often use the same kind of cover for both voltmeters and ammeters. The word volts, voltmeter,

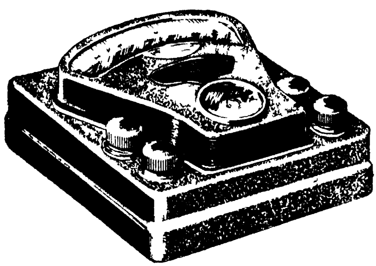


Fig 5. Outside View of Voltmeter

amperes, or ammeter are usually printed on the front of the meter in order to tell whether it is to be used as a voltmeter or an ammeter.

Another word that is more often used in electrical work when referring to electrical pressure is **voltage.** Instead of speaking of the electrical pressure forcing the current through a wire, we usually speak of it as the **voltage.** Also, instead of speaking of the electrical pressure of a certain generator, we usually speak of the **voltage** of this generator.

RESISTANCE

We have seen that when it rains, the water runs off the side of a hill into a small ditch, and then several of these small ditches unite and form a larger ditch. Several of the larger ditches finally unite and form a still larger ditch. The water flows into these

ditches instead of over the surface of the ground, because the ditches do not hold the water back but provide an easy place for it to flow.

There are some metals or substances that allow electric current to flow through them easier than through other substances. Every substance or metal, however, has a tendency to resist or hold back the electric current to some extent from flowing through it, just as the banks of the ditches resist the tendency of the water to flow out of the ditches.

OHM

In order to be able to compare the resistance of the flow of electric current offered by one metal or substance with that offered by another metal or substance, it is necessary to have a word that will describe this property, just as we use the inch or foot when referring to the length of an object.

The electrical word used to compare the resistance offered to the flow of electricity by one substance with another is the **ohm.** Thus, we speak of the resistance of a radio rheostat, Fig. 6, as being 10 ohms, 20 ohms, 30 ohms, and so forth. This means that the rheostat having a resistance of 20 or 30 ohms will offer two or three times as much opposition to the flow of electric current as the 10-ohm rheostat. In electrical work whenever we see the word **ohm,** we think of resistance, because that word is used in speaking of the ability of any substance or object to resist or hold back the flow of electric current. The higher the resistance, the greater is the holding back power.

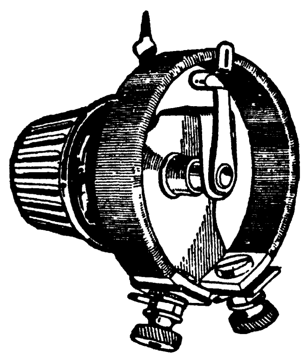


Fig 6 Radio Rheostat
Courtesy of Herbert H. Frost, Inc., Chicago

INSULATORS AND CONDUCTORS

If you pour a pail of water into a hollow spot in a pile of broken rock or large gravel, Fig. 7, you will find that the water seeps through the crevices of the rock and disappears very quickly; if you pour a pail of water in a hollow spot in a pile of sand, the

water disappears slowly; while if you pour a pail of water into a hollow spot in a pile of clay, Fig. 8, the water will remain for a day or two before it disappears in the clay. Therefore, it is evident that the clay offers a higher or greater resistance to the passage of water through it than the sand or gravel offers.

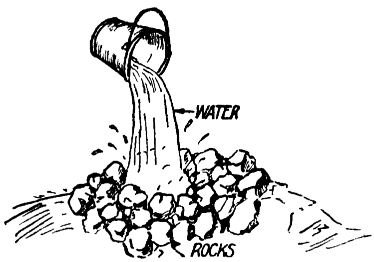


Fig. 7 Pouring Water on a Pile of Rocks

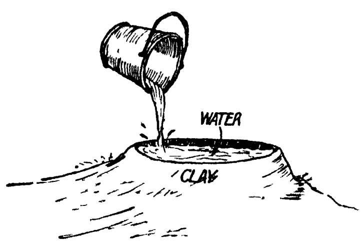


Fig. 8. Pouring Water on a Pile of Clay

TABLE I

Good Insulators (Very High Resistance)	Poor Insulators and Poor Conductors	Conductors
Porcelain	Moist Air	Water
Rubber	Carbon	Nichrome Wire
Glass	Wet Cotton	Steel
Marble	Wet Wood	Iron
Dry Air	Graphite	Tin
Dry Cotton		Zinc
Dry Wood		Aluminum
The resistance of the substance at the bottom of each column is lower than those higher up in the column.		Copper, Silver } Good Conductors (Very Low Resistance)

Any substance that offers a very high or very great resistance to the passage of electric current through it is called an **insulator.** Porcelain offers a resistance to the passage of electric current through it that is 1,300,000,000,000,000,000,000 times as great as that of copper. Dry wood has a resistance that is more than 1,000,000,000,000 times as great as that of copper. Carbon has a resistance that is 2400 times as great as that of copper, while graphite has a resistance 500 times as great as that of copper. The resistance of

Nichrome wire, which is used in electric toasters, flatirons, and stoves, is about 66 times that of copper. The electrical resistance of copper wire is about $1\frac{1}{10}$ times that of silver; of aluminum, 2 times that of silver; and of iron and steel, about 7 to 10 times that of silver.

Silver is the best electrical conductor but it is very expensive, its cost being many times that of copper. Aluminum, zinc, and tin are fair conductors but they cost much more than copper. Therefore, as copper is the cheapest electrical conductor, it is used almost entirely in electrical work for carrying an electric current. Thus,

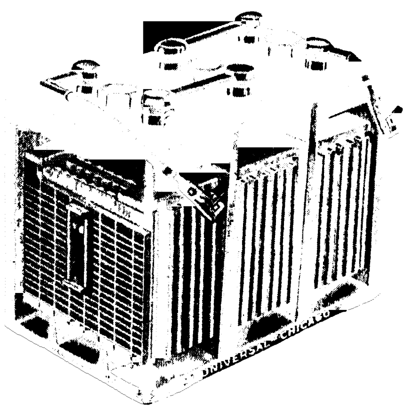


Fig 9 Six-Volt Storage Battery

in electrical work whenever the word wire is written or spoken of, it means copper wire unless some other kind of metal or material is mentioned.

Table I gives a list of substances often used in electrical work as insulators or conductors. Thus, porcelain, rubber, glass, and so forth, are considered good insulators. Carbon, moist air, graphite, etc., are very poor insulators and also poor conductors. Carbon and graphite are sometimes used when it is desired that the conductor should have a very high resistance. Water and all common metals are classified as conductors in comparison with other substances. However, in comparing Nichrome wire with copper, the Nichrome wire would not be considered as good a conductor as copper. Table I will prove of assistance both in determining what

to use as a conductor of electricity and what to use as an insulator of electricity.

SOURCES OF ELECTRIC CURRENT

While the action of electricity is probably explained better by the water analogy or illustration than by any other method, the student must not carry this too far or form any opinion that electricity has weight and density and all the other characteristics of water. However, the steady even flow in one constant direction of a water system is very similar to the flow of an electric current which is produced by a battery, Fig. 9.

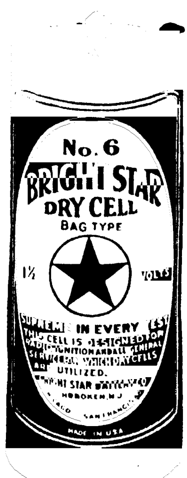


Fig. 10. No. 6 Dry Cell

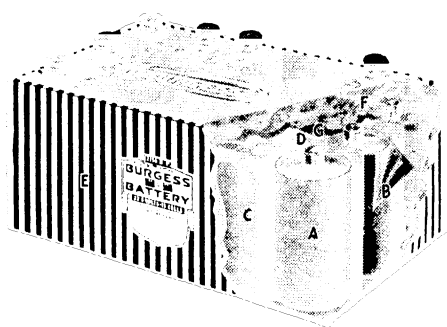


Fig. 11. Cutaway View of "B" Battery
A—Zinc can be made of pure metal; B—Wrapper around cell for insulation; C—Sealing material; D—Partition between cells prevents chafing and aids insulation; E—Waterproof insulating casing; F—Seal over top—strength and insulation; G—Webbing seal—adds strength.
Courtesy of Burgess Battery Company, Freeport, Illinois

BATTERY CURRENT—ELECTRICAL CURRENT BY CHEMICAL ACTION. You no doubt are familiar with the battery or dry cell used in radio work Figs. 10 and 11, or the small one used in the flashlight, Fig. 12. This type of dry cell produces a fixed voltage regardless of its size. The maximum voltage of any single cell is 1½ volts. Some flashlights are powered with two-cell and some with three-cell batteries.

The dry cell, Fig. 13, is not really dry, since the carbon plate is imbedded in a moist state contained in a cylindrical can made of

zinc. The paste consists usually of crystals of ammonia chloride, three parts of plaster of Paris, one part of zinc oxide, one part of zinc chloride, and two parts of water. The plaster of Paris is used to give the paste rigidity. It is the action of the ammonia chloride on the zinc which produces the current of electricity.

In all batteries there is a chemical change of some of its parts going on during operation, and it is this change or consumption of materials caused by chemical action that furnishes the energy to

Fig 12 Flash Light
Courtesy of Bright Star Battery Company

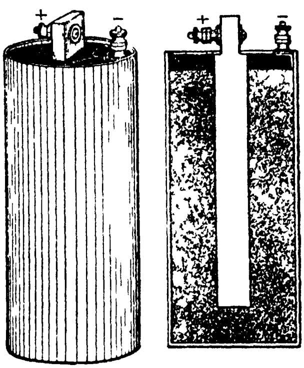


Fig. 13. Typical Dry Battery

drive an electric current through the cell and the bell, etc., to which it may be connected. *The path which the current of electricity takes from the battery, through the wires and bell or lamp, and back to the battery is called a circuit.* Fig. 14 shows a hydraulic system, starting with the centrifugal pump which pumps water through the pipes, drives the water wheel, and returns it by a pipe to the water reservoir. You will note that the water in the reservoir has traveled a complete circuit. Fig. 15 shows an electric circuit, starting from a battery, going along a wire to drive a small motor, and returning by another wire to the battery, thereby also making a complete circuit.

When the switch is turned on, the flow of electricity from a dry cell or storage battery is from the positive terminal, often marked plus (+), along the circuit to the negative terminal, often marked minus (—). We find that this current flows steadily along the wires in the circuit in one constant direction, and the current will also come up to the full amount of amperes and stay at this point while the battery stands up to its rated pressure or until the circuit

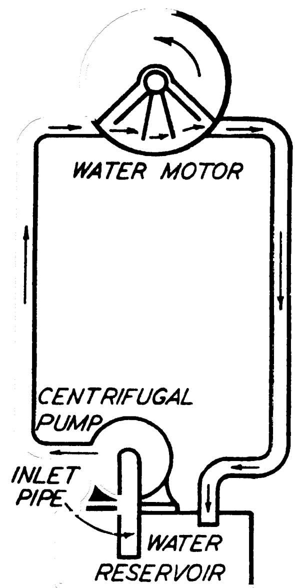


Fig. 14. Flow of Water through a Pipe System

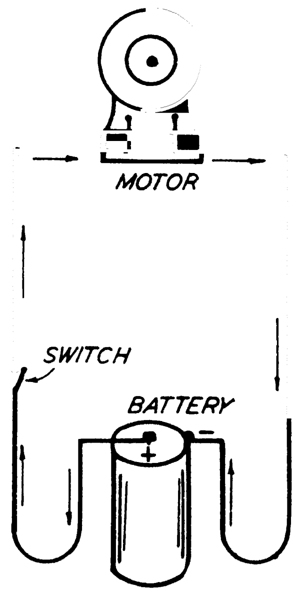


Fig. 15. Flow of Electric Current through a Circuit

is disturbed, *so this current is a steady current and it is in one direction.*

The amount of current in a circuit is determined and limited by the capacity of the wires and devices to carry current in that circuit and not by any action or reaction of the battery.. We must assume here, of course, a battery large enough to do the work properly. The pressure needed for a circuit is always examined before the selection of the battery. In doing this, careful checking of the voltage rating stamped upon the lamp or other device of the circuit must be made. When this battery is applied to the circuit,

the voltage of the circuit will be the voltage of the battery and will be maintained at this pressure so long as the battery is not loaded beyond its capacity. Therefore, current has a constant voltage.

We can now see that a battery current has the following characteristics. *It flows in one direction; it is steady; and it has a constant voltage.*

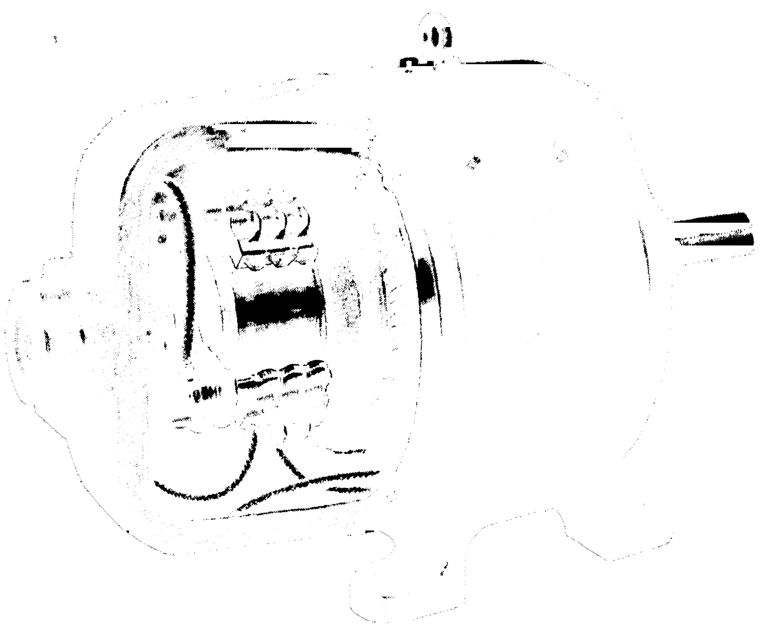


Fig. 16. Direct-Current Generator

ELECTRICAL CURRENT BY MECHANICAL ACTION. Electricity gradually came to be accepted in industry as its old uses were developed and new uses were found for it; and it became evident that the battery as a source of power was equal neither physically nor economically to the demand which was placed upon it. Bear in mind that the battery at this stage of development was not the highly perfected storage battery of today. It was not a storage battery at all, but a collection of many chemical cells. By the time the users of electricity began to realize that the battery was

lacking as a source of power for the growing steady demands which were made upon it, the scientist in his laboratory had not been idle. He had discovered certain things about mechanical production of electricity.

In 1831, Farraday discovered that if a wire which had no current in it were moved through a magnetic field, a current would be induced or developed in the wire. Perhaps this does not mean much to you, perhaps it did not mean so much to the scientist who discovered it, but finally there came a time when test tubes and chemicals were set aside, and magnets, wires, and coils began to take their places. *Electricity was passing from the chemical into the dynamic stage,* thus was born the dynamo—the mechanical generator of electricity, Fig. 16. Today it is one of the most important machines of industry, for the mechanical generator is not confined in its development as the battery was, in fact, insulation is now practically the only limitation to extreme voltages which may be placed upon the building of generators.

Chapter II

Principles of a Generator

ESSENTIAL PARTS OF A DYNAMO. The dynamo is a machine for converting mechanical energy into electrical energy or electrical energy into mechanical energy. When it is used in transforming mechanical into electrical energy, it is called a generator; and when it transforms electrical into mechanical energy, it is called a motor. The great majority of dynamos have the following essential parts: the magnetic field; the armature winding; the commutating and collecting devices (not required in all machines—the squirrel-cage induction motor, for example); and the necessary mechanical structure, such as bed plate, iron composing the magnetic circuit and its supporting structure, armature core, bearing supports, etc.

Magnetic Field. The function of the magnetic field is to provide a magnetic flux, which is cut by the inductors forming the armature winding.

Armature Winding. The armature winding is composed of a large number of wires, called inductors, in which an electromotive force (e.m.f.) or electrical pressure is induced when there is a relative movement of these inductors with reference to the magnetic field of the machine.

Commutator or Collecting Rings. The function of the commutating and collecting devices is to bring about the necessary reversal of connections between the various elements composing the armature winding and the external circuit, and at the same time to provide the necessary continuous electrical connection between the circuits on the moving part of the machine and the outside circuits.

Mechanical Parts. The function of the various mechanical parts is obvious, and the iron composing the magnetic circuit often performs a mechanical function in the construction of the machine, as, for example, the iron used in the construction of the armature

core serves as a mechanical support for the armature windings.

In commercial continuous-current machines, the field magnet is nothing more than a simple electromagnet which remains stationary, but the armature is a great deal more complex and always rotates. In alternating-current machines either the armature or field may be stationary. Continuous-current machines always require a commutator, which is mounted on the same shaft as the armature, while the alternating-current machines are provided with slip rings when an electrical connection must be established between the rotating part of the machine and an outside circuit.

The development of the various forms of armature windings

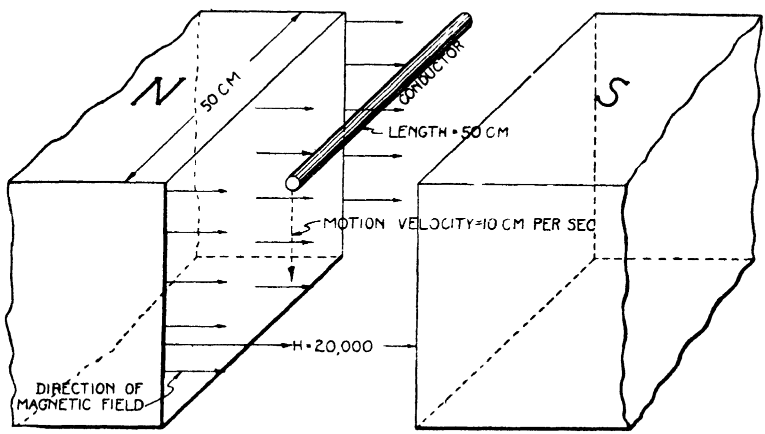


Fig. 1. Horizontal Conductor Moving Downward across a Uniform Magnetic Field—Motion Perpendicular to Field

for both continuous- and alternating-current machines will be discussed in the following sections.

PRODUCING AN E.M.F. BY CUTTING MAGNETIC LINES OF FORCE. When a conductor and a magnetic field are caused to move relative to each other, so that the imaginary lines of force that are supposed to compose the magnetic field are cut by the conductor, there will be an e.m.f. induced in the conductor.

E.M.F. Depends on Rate Lines Are Cut. The value of this induced e.m.f. at any instant will depend upon the rapidity with which the lines of force are being cut by the conductor at that particular instant. If the lines of force are being cut at a perfectly

uniform rate, that is, if the same number are cut in each succeeding fractional part of a second, say one hundredth part of a second, and there is a total of 100,000,000 lines cut in one second, then there will be an e.m.f. of one volt induced in the conductor. Thus if a horizontal conductor 50 inches long were moved downward across a horizontal magnetic field whose intensity is 20,000 lines of force as indicated in Fig. 1, at a uniform velocity of 10 inches each second, all the magnetic lines in the area 10×50 inches would be cut in one second. Sizes there are 20,000 magnetic lines passing through each unit of area, then the total number of magnetic lines cut by the conductor in one second will be equal to $10 \times 50 \times 20000$, or 10,000,000. Dividing 10,000,000 by 100,000,000 gives 0.1 volt, the value of the e.m.f. induced in the conductor.

If the conductor be moved at a greater velocity, say twice as fast, then the e.m.f. induced will be equal to twice the stated value, and if its velocity be decreased there will be a corresponding decrease in the induced e.m.f. If the strength of the magnetic field be increased or decreased in value, there will be a corresponding increase or decrease in the value of the induced e.m.f. Likewise, if the length of the conductor in the magnetic field, or that part of the conductor which is actually cutting lines of force, be increased or decreased, there will be a corresponding increase or decrease in the value of the induced e.m.f.

If this conductor be made to form part of a closed electrical circuit, there will be a current of electricity produced in the circuit due to the e.m.f. induced in the conductor.

RIGHT-HAND RULE. There is a definite relation between the direction of the magnetic field, the direction of motion of the conductor, and the direction of the induced e.m.f., which is as follows: If the first and second fingers and the thumb of the right hand be placed at right angles to each other and in such a position that the first finger points in the direction of the magnetic field and the thumb points in the direction of motion, then the second finger will point along the conductor in the direction of the induced e.m.f. The direction of the induced e.m.f. will be reversed if the direction of the motion or the direction of the magnetic field be reversed. If the direction of the magnetic field

and the motion both be reversed, then the direction of the induced e.m.f. will remain the same.

The motion of the conductor in Fig. 1 is perpendicular to the direction of the magnetic field, and, as a result, more magnetic lines are cut by the conductor when it moves a certain distance

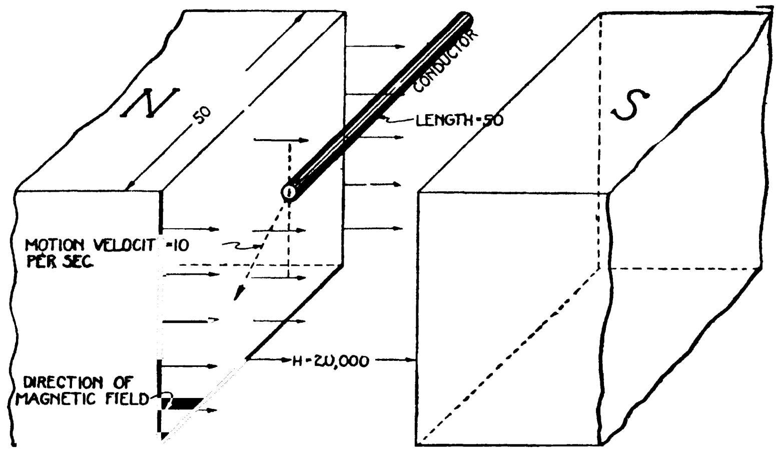


Fig 2 Horizontal Conductor Moving Downward across Uniform Magnetic Field—Motion Not Perpendicular to Field

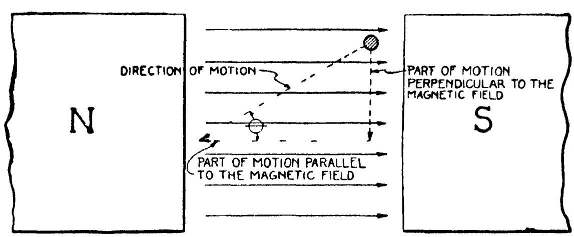


Fig 3 Motion of Conductor Resolved into Two Components—One Perpendicular to Field and One Parallel to Field

along its path than would be cut if the motion of the conductor were along a path making an angle of less than 90° with the direction of the magnetic field, Fig. 2.

In Fig. 2 it is that part of the velocity of the conductor perpendicular to the direction of the magnetic field that determines the rate of cutting of the magnetic lines. This part of the velocity of the conductor is indicated by a dotted vertical line downward from the conductor, Fig. 2. It is also illustrated in Fig. 3 where the

diagonal line "direction of motion" is divided up into "part of motion perpendicular to the magnetic field" and "part of motion parallel to the magnetic field."

When the angle between the direction of motion of the conductor and the magnetic field is 30° as in Fig. 3, that "part of the motion perpendicular to the magnetic field" is only one-half of the "direction of motion." This can be verified by measuring the two dotted lines in Fig. 3. A change in the angle θ from 30° to 45° or 60° will cause a greater part of the "direction of motion" to be "perpendicular to the magnetic field." When this angle θ becomes 90°,

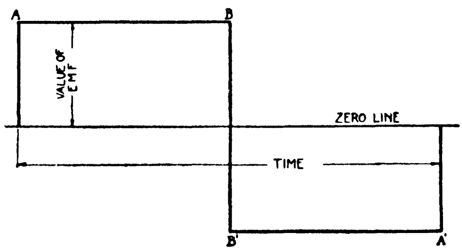


Fig. 4. Curve Representing Variation in Value of Electromotive Force Induced in a Conductor That Is Moved Back and Forth across a Uniform Magnetic Field at a Constant Velocity

all the "direction of motion" will be "perpendicular to the magnetic field." Thus that part of the motion that is perpendicular to the magnetic field has to be determined before the voltage can be determined.

SIMPLE GENERATOR

ANALYSIS OF OPERATION. Straight Conductor. When the conductor, Fig. 1, has moved downward a sufficient distance to be out of the magnetic field, there will be no e.m.f. induced in it, as it continues to move on down, for there will be no magnetic lines of force cut by the conductor. Now, in order that the conductor may continue cutting the magnetic lines of force, it will be necessary for the motion of the conductor to be reversed when it reaches the edge of the magnetic field in its downward travel; that is, the motion of the conductor must be alternately up and down across the magnetic field. If the strength of the magnetic field is uniform in the region in which the conductor moves and the velocity of the

conductor is constant and the direction of its motion is reversed instantly, then the variation in the e.m.f. induced in the conductor may be represented graphically as shown in Fig. 4. Assume that

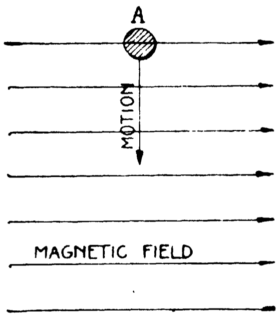


Fig. 5. Conductor Entering Magnetic Field and Moving Downward across Same

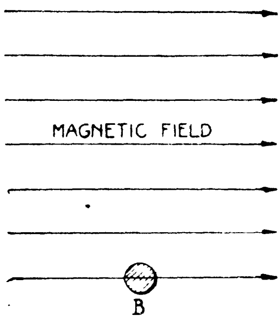


Fig. 6. Conductor at Lower Edge of Magnetic Field

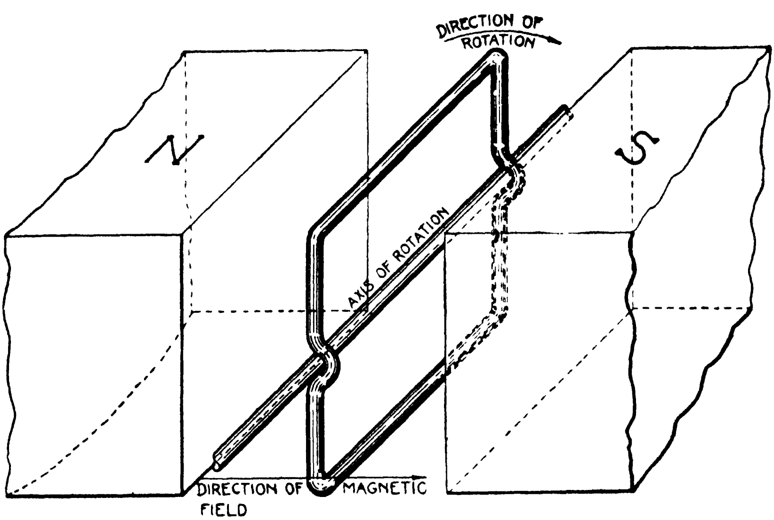


Fig. 7. Closed Loop of Wire Revolving in a Uniform Magnetic Field

the conductor starts from its uppermost position in the magnetic field, as shown at *A*, Fig. 5, and moves at a constant velocity downward across the magnetic field to its lowermost position, as shown at *B*, Fig. 6. During this time the conductor is cutting the magnetic lines at a constant rate for all positions and, as a result, the e.m.f.

induced in it is constant, as represented by the upper part of the line *AB*, Fig. 4. The height of the horizontal line *AB* above the zero line is a measure of the e.m.f. induced in the conductor. Now when the conductor reaches the lowermost position, it immediately starts to move upward across the magnetic field at the same rate it was originally moving downward across the field, and, as a result, the value of the induced e.m.f. will be the same but its direction will be exactly opposite what it was originally. This fact is shown

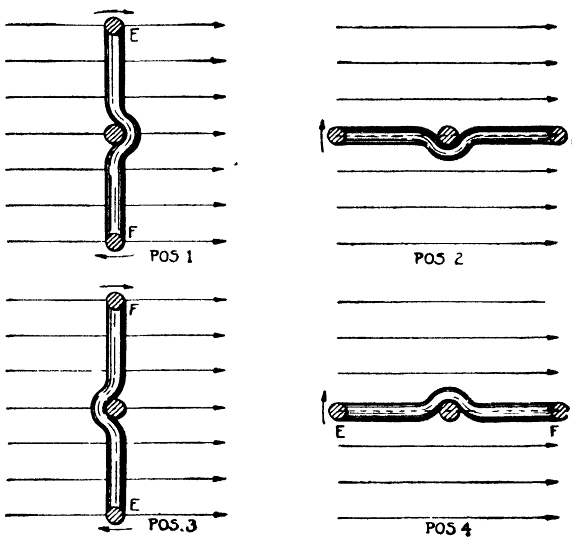


Fig. 8. Four Different Positions of a Loop as It Revolves in a Magnetic Field

diagrammatically in Fig. 4 by the line *B′A′*, which is parallel to the zero line and exactly the same distance below the zero line as the line *AB* is above the zero line. The lengths of the lines *AB* and *B′A′* are drawn to represent time to any convenient scale; thus each inch may correspond to one second, etc.

Action of Loop. The arrangement just described may be greatly improved upon by revolving a loop of wire in a magnetic field, as shown in Fig. 7. Four positions of the loop are shown in cross-section in Fig. 8, and the e.m.f. induced in the loop for these different positions may be determined as follows: In position *1* the plane of the loop is perpendicular to the direction of the mag-

netic field, and if the loop be rotated a small angle about its axis, there will be no e.m.f. induced in it because there are no magnetic lines cut by any part of the loop. The two sides of the loop will be moving parallel to the magnetic field, and hence cutting no lines of force; while the planes in which the two ends move are parallel to the direction of the magnetic field, and hence the ends will never cut across any of the lines of force forming the magnetic field, regardless of the angular position of the coil, so long as the axis of the loop is perpendicular to the direction of the magnetic field.

In position *2* the plane of the loop is parallel to the magnetic field and the two sides of the loop are moving perpendicular to the magnetic field for an instant while the loop is in this position. Since the sides of the loop are moving perpendicular to the direction of the magnetic field, when the loop is in position *2* they will be cutting the magnetic lines at the greatest possible rate.

In position *3* the plane of the loop is perpendicular to the direction of the magnetic field and the e.m.f. induced in the two sides is zero, for the same reasons as those given for position *1*. In position *4* the plane of the loop is parallel to the direction of the magnetic field and the two sides are moving perpendicular to the direction of the magnetic field just as explained for position *2*. In position *2*, however, the side *E* is moving downward across the magnetic field and the side *F* is moving upward across the magnetic field, while in position *4* just the reverse is true; that is, side *E* is moving upward across the magnetic field, and side *F* is moving downward across the magnetic field. The e.m.f. induced in the two sides will be in opposite directions for all positions of the loop as you look along the two sides, but it will be observed that they are acting together around the loop rather than opposing each other, for all positions of the loop.

From position *1* to position *3*, the side *E* is moving downward across the magnetic field and the side *F* is moving upward across the field, while from position *3* back to position *1* the side *E* is moving upward across the magnetic field and the side *F* is moving downward. As a result of this relation between the direction of motion of the sides of the loop and the direction of the magnetic

field, there will be an electrical pressure induced in the loop which will act around the loop in a certain direction while the loop is rotating from position *1* to position *3* and around the loop in the opposite direction while rotating from position *3* to *4* and on back to position *1*, or the starting point.

VARIATIONS OF E.M.F. IN ONE REVOLUTION. The value of the e.m.f. in the loop does not remain constant, but changes in value as the position of the loop in the magnetic field changes, the reason being that the velocity of the sides across the magnetic lines

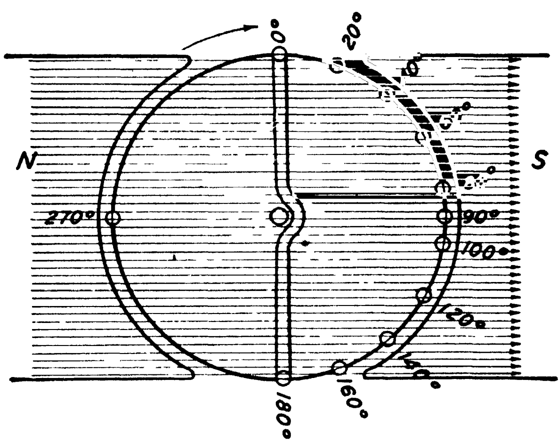


Fig. 9. Diagram Showing Variations in Number of Lines of Force Cut During a Revolution of an Armature Conductor

of force for a certain constant angular rotation of the loop is continuously varying in value. This can be proved easily by counting the number of fine lines the loop or conductor crosses in Fig. 9 when moving from 0° to 20° and comparing them with the number of lines crossed for similar distances in other parts of the revolution. They are as follows:

From 0° to 20° — 1 Line	From 100° to 120° — 6 Lines
From 20° to 40° — 4 Lines	From 120° to 140° — 5 Lines
From 40° to 60° — 5 Lines	From 140° to 160° — 4 Lines
From 60° to 80° — 6 Lines	From 160° to 180° — 1 Line
From 80° to 100° — 7 Lines	....

The number of lines crossed as the conductor or loop rotates from 180° through 270° to 360° is the same as 0° to 180°. You

could make Fig. 9 very large in size and draw many fine lines and get more accurately the number of lines crossed in different parts of a revolution. In fact, you could determine the number of lines of force crossed for each degree from 1° to 90°. However, this work is not necessary because the mathematicians have prepared tables that will give us these comparisons. They call these tables "sine of an angle" and use a symbol like this θ as an abbreviation to indicate the angle. These tables are often called *"Sine Tables"* and are given in all books on trigonometry. By using these sine tables you can easily determine what part of the maximum number of lines of force are being crossed at any particular angle.

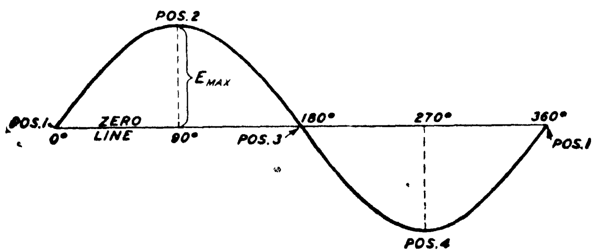


Fig. 10. Curve Representing Variation in Value of Electromotive Force Induced in a Loop That Is Rotated at a Uniform Angular Velocity in a Uniform Magnetic Field

Since the value of e.m.f. or voltage produced in the conductors depends upon the number of "lines of force" crossed, these sine tables will tell us what part of the maximum voltage is produced at any position of the conductors or loop. These values can be plotted as a curve, Fig. 10, in which the maximum voltage produced (abbreviated E_{max}) in position 2 of the loop, Fig. 8, is multiplied by the sine of the different number of degrees. This curve, Fig. 10, is called a sine curve because the height of the curve above the zero line at different places is obtained by the use of these sine tables. The distances along the zero line, Fig. 10, are divided into degrees from zero to 360°, but only 90°, 180°, 270°, and 360° are marked; these correspond to the position of the loop in Fig. 8. The distances along the zero line correspond to the values of the angle θ. Such a curve is called a sine curve.

EFFECT OF MORE LOOPS. The e.m.f. may be increased by adding more turns to the loop and connecting these turns in series

so that the e.m.f. induced in the different turns acts in the same direction around the loop.

The complete set of positive and negative values represented in Fig. 10 constitutes what is called a cycle. A complete set of positive or negative values constitutes what is called an alternation. There are always twice as many alternations as there are cycles. The number of complete cycles that occur in one second is called the frequency. In Fig. 10 one revolution of the loop constitutes a

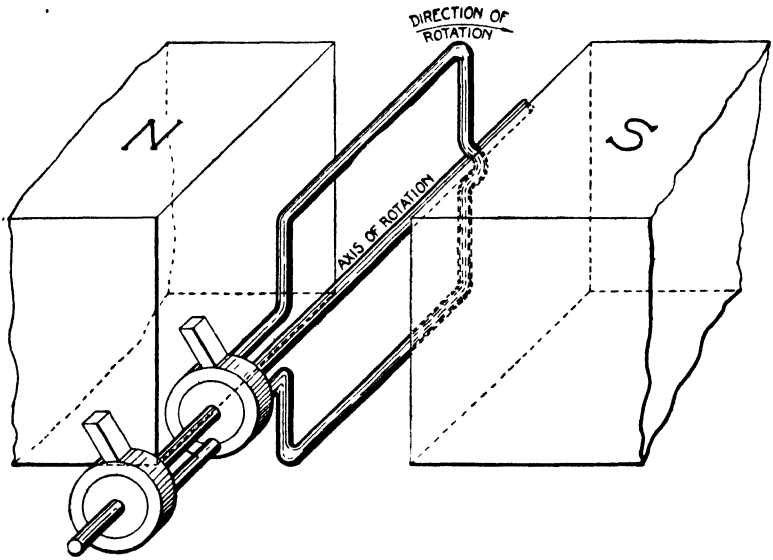


Fig. 11. Simple Alternating-Current Generator

cycle, or two alternations; and if the loop is made to revolve at the rate of 60 revolutions per second, the frequency of the induced e.m.f. will be 60 cycles.

FUNCTION OF SLIP RINGS. In order to make use of the e.m.f. generated in the loop, Fig. 7, in producing a current in an electrical circuit, it is necessary to provide some means of connecting the loop in series with the circuit in which the current is to be produced. Such an electrical connection may be provided by opening up the loop and connecting the two ends thus formed to two continuous metal rings, mounted on the axis of the loop and insulated from each other. Upon these rings are two metal or carbon

brushes, connected to the external circuit, as shown in Fig. 11. Such a device constitutes a simple alternating-current generator.

FUNCTION AND OPERATION OF TWO-PART COMMUTATOR. As the loop of wire in Fig. 11 is made to revolve, an e.m.f. will be induced in it, and this e.m.f. will reverse in direction

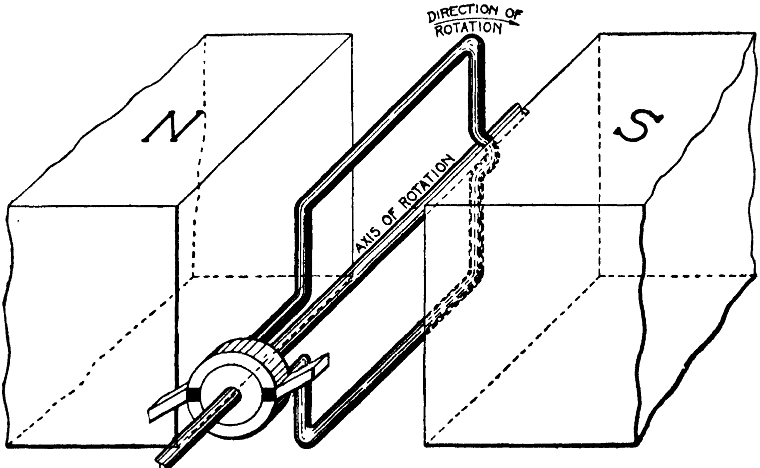


Fig. 12. Simple Direct-Current Generator

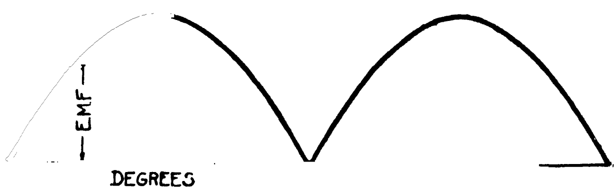


Fig. 13. Curve Representing Variation in Value of Electromotive Force between Brushes of Direct-Current Generator Shown in Fig. 12

twice every revolution, as shown by the curve in Fig. 10. If the external circuit be closed, the alternating e.m.f. induced in the loop will produce an alternating current in the circuit. Such a current is not suitable for all purposes, as, for example, charging storage batteries, and must be changed to a unidirectional or direct current. It is the function of the commutator to change the alternating current in the loop into a direct current in the external circuit and at the same time provide the necessary electrical connections between the loop and external circuit.

The simplest form of commutator consists of a metal ring divided into two equal parts and mounted on a tube of insulating material, the two halves of the ring being insulated from each other. Each half of the ring should be connected to one of the ends of wire formed by opening up the loop, Fig. 12. The metal parts composing the commutator are called segments. The two segments in the commutator are shown in Fig. 12. The electrical connection to the external circuit is made by means of suitable brushes which make electrical contact with the segments of the

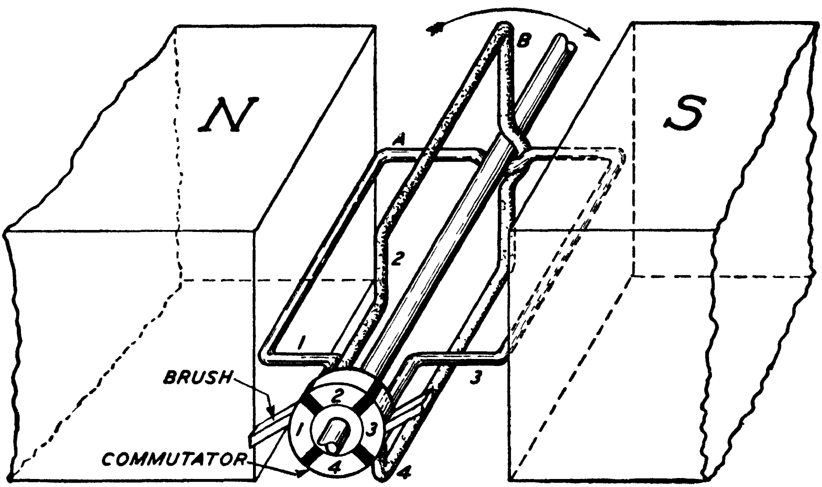


Fig. 14. Direct-Current Generator Composed of Two Loops of Wire and a Commutator of Four Segments

commutator. Two brushes are required with a two-part commutator and single loop, as shown in Fig. 12, and these brushes should be equally spaced on opposite sides of the commutator, and in such a position that the insulation between the segments of the two-part commutator is exactly in the middle of the brushes when the plane of the loop is perpendicular to the direction of the magnetic field, or the induced e.m.f. in the loop is zero. A two-part commutator of this kind will reverse the connections of the loop of wire with respect to the external electrical circuit when the e.m.f. in the loop is zero and the e.m.f. acting on the external circuit always will be in the same direction and may be represented graphically by a curve

such as the one shown in Fig. 13. This kind of an e.m.f. is called a pulsating e.m.f. because it pulsates in value at regular intervals; it is, however, continuous in direction. In order to produce an e.m.f. nearer constant in value more commutator segments and loops of wire must be used.

OPERATION OF FOUR-PART COMMUTATOR AND TWO LOOPS OF WIRE. The fluctuation in the value of the e.m.f. between the brushes with the arrangements shown in Fig. 12, can be reduced by using two more commutator segments and a second loop. In this case the metal ring is cut in four parts instead of two, thus forming a commutator composed of four segments instead of two. The two loops are placed at right angles to each other and the terminals of each loop are connected to commutator segments that are opposite to each other instead of adjacent to each other. The connections of the loops and segments are shown in Fig. 14. Two brushes are required, and they should be placed exactly opposite each other and in such a position around the commutator that they pass from one segment to the next when the planes of the two loops are making angles of 45 degrees with a plane perpendicular to the direction of the magnetic field. The proper position of the brushes is shown in Fig. 14. Let us now consider the operation of this machine. Starting with loop *A* parallel to the magnetic field, loop *B*, which is at right angles to loop *A*, will be perpendicular to the direction of the magnetic field. When the loops are in this position the brushes should be in the center of the segments connected to loop *A*. Now as the combination of loops and commutator (called the armature) rotates, the e.m.f. induced in loop *A* decreases in value and the e.m.f. induced in loop *B* increases in value (it is to be remembered at the start the e.m.f. in *A* is at its maximum value and the e.m.f. in *B* is zero). When the armature has turned through an angle of 45 degrees, the commutator segments connected to loop *A* move from under the brushes and the commutator segments connected to loop *B* move under the brushes. This results in loop *B* now being connected in series with the external circuit instead of loop *A*. Loop *B* will remain in electrical connection with the external circuit for the next 90 degrees' rotation of the armature, or one quarter turn, when the segments connected to

B move from under the brushes and those connected to *A* move under the brushes. From the above statements and a careful inspection of Fig. 14 it is apparent that the loops *A* and *B* are alternately connected to the external circuit, and each time either of them is connected it is for one quarter of a revolution of the armature. The e.m.f. between the brushes varies in value, but it will never drop to zero value as with the single loop. The connections of the loops are changed when they are making an angle of 45 degrees with a plane perpendicular to the direction of the magnetic field and the e.m.f.'s induced in the loops at this instant are equal in value and equal to 0.707 of the maximum e.m.f. in-

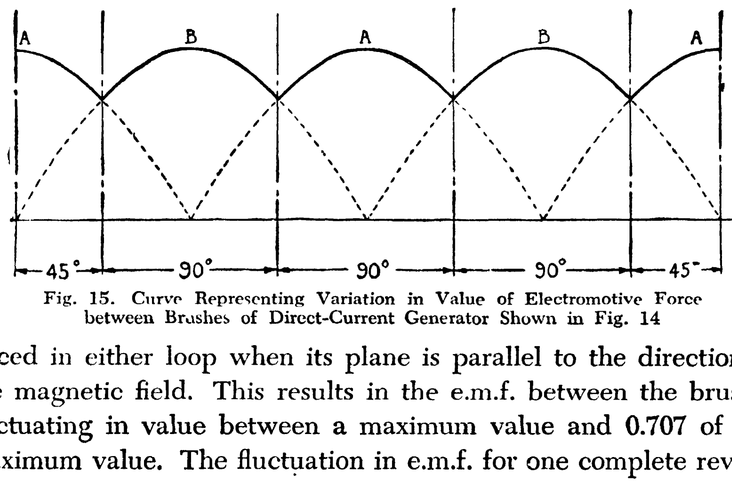


Fig. 15. Curve Representing Variation in Value of Electromotive Force between Brushes of Direct-Current Generator Shown in Fig. 14

duced in either loop when its plane is parallel to the direction of the magnetic field. This results in the e.m.f. between the brushes fluctuating in value between a maximum value and 0.707 of this maximum value. The fluctuation in e.m.f. for one complete revolution of the armature is shown in Fig. 15.

OPERATION OF SIX-PART COMMUTATOR AND THREE LOOPS OF WIRE. The fluctuation in the value of the e.m.f. between the brushes with the arrangement described in the preceding section may be decreased by using three loops of wire and a commutator composed of six segments. The terminals of each loop should be connected to two segments exactly opposite each other and the brushes should be exactly opposite each other and in such a position that they are in the center of the commutator segments connected to a loop when that loop is in a position parallel to the direction of the magnetic field, or when the e.m.f. induced in the loop is at its maximum value. The arrangement of the loops,

brushes, and commutator segments is shown in Fig. 16. Now as the armature rotates, the e.m.f. induced in loop *A* decreases in value, the e.m.f. induced in *B* decreases in value, and the e.m.f. induced in *C* increases in value. When the armature has turned

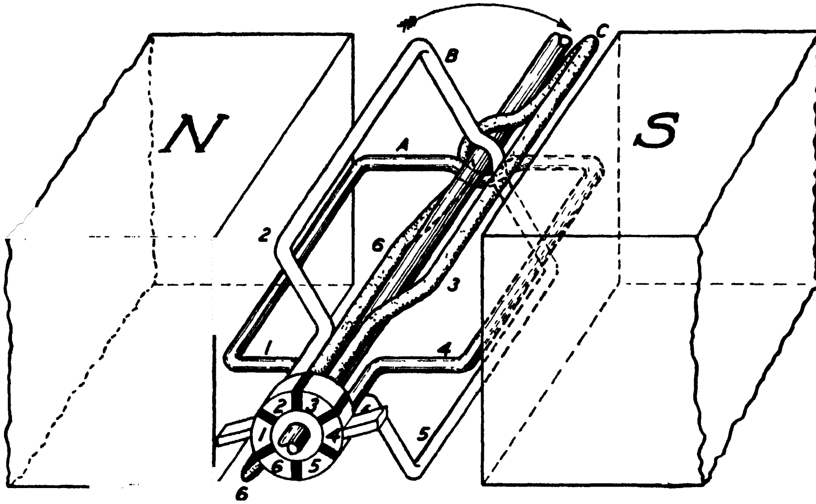


Fig. 16. Direct-Current Generator Composed of Three Loops of Wire and a Commutator of Six Segments

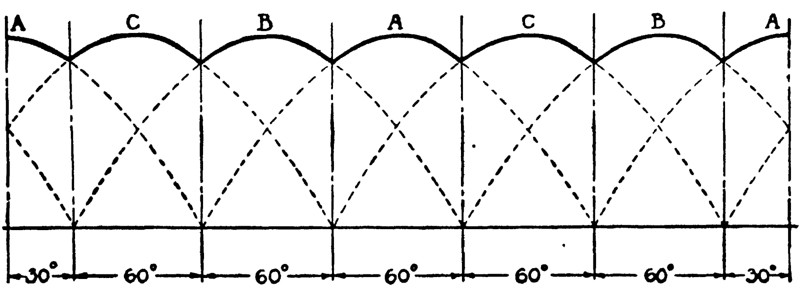


Fig. 17. Curve Representing Variation in Value of Electromotive Force between Brushes of Direct-Current Generator Shown in Fig. 16

through an angle of 30 degrees the segments connected to the loop *A* move from under the brushes, and the segments connected to loop *C* come into contact with the brushes and remain in contact for a rotation of the armature of 60 degrees, or one-sixth revolution. When the segments connected to loop *C* leave contact with the brushes, the segments connected to loop *B* make contact, and

remain in contact for one-sixth revolution, then loop *A* comes into contact again for one-sixth revolution; then loop *C* for one-sixth revolution, loop *B* for one-sixth revolution, and back to loop *A* for an angular movement of 30 degrees. This brings the armature back

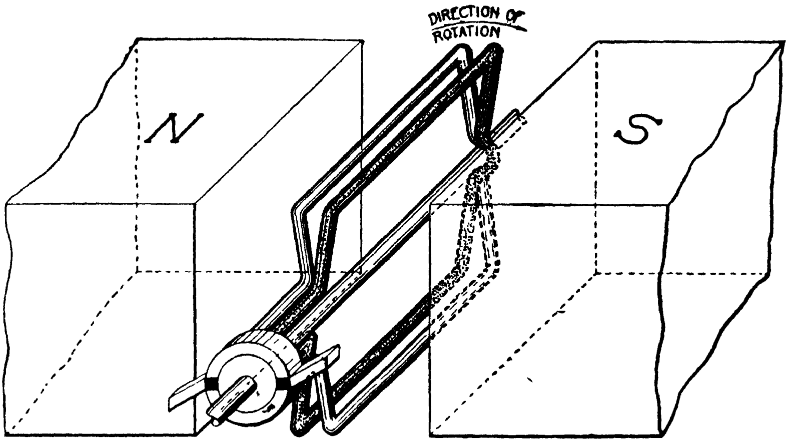


Fig. 18. Direct-Current Generator Composed of Two Loops of Wire and a Commutator of Two Segments

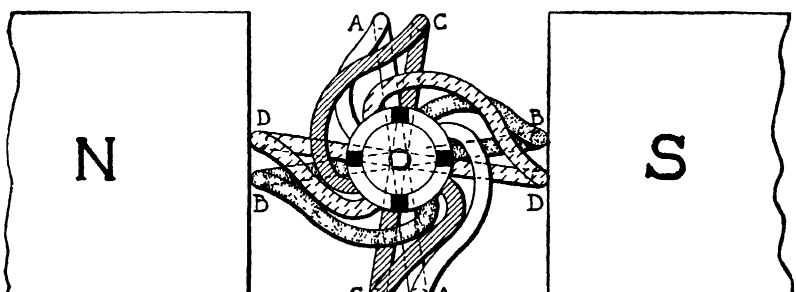


Fig. 19. Direct-Current Generator Composed of Four Loops of Wire and a Commutator of Four Segments

to the starting point. The fluctuation in e.m.f. for one complete revolution of the armature is shown in Fig. 17.

OPERATION OF TWO-PART COMMUTATOR AND TWO LOOPS OF WIRE. Two loops of wire may be connected in parallel between two commutator segments as shown in Fig. 18. The e.m.f. between the brushes will be the same as though a single loop of wire were used, but the current the armature is capable of delivering will be doubled if the wire used in winding the loops

is of the same size as that used in winding the single loop. The variation in the e.m.f. between the brushes for such a combination is shown in Fig. 13.

OPERATION OF FOUR-PART COMMUTATOR AND FOUR LOOPS OF WIRE. An armature may be formed by interconnecting four loops of wire and four commutator segments. The connections are shown in Fig. 19. Each loop has its terminals connected to adjacent commutator segments. The brushes must be broad enough to bridge the insulation between adjacent segments, and they are mounted on the commutator in such a position that they short-circuit the loops when the sides of the loops are moving parallel to the magnetic field.

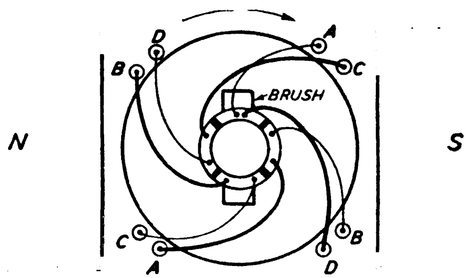


Fig. 20. Position of Conductors and Brushes after the Armature in Fig. 19 Has Rotated One Eighth of a Revolution

An inspection of Fig. 19 will assist you in understanding the following statements. When the armature is in the position shown in Fig. 19, the e.m.f. induced in the loops *A* and *C* is zero, and the e.m.f. induced in the loops *B* and *D* is a maximum. Of course, loops *A* and *C* are short-circuited by the brushes, but no damage results as there is no e.m.f. induced in these loops in this position. Loops *B* and *D* are connected in parallel between the brushes, and the e.m.f. between the brushes is that induced in either loop *B* or *D*, which is supposedly the same. Now, as the armature rotates from the position shown in Fig. 19, the e.m.f. in loops *B* and *D* decreases in value and the e.m.f. in the loops *A* and *C* increases in value, starting with zero. A small angular rotation of the armature results in the short-circuit of the loops *A* and *C* being removed, and the loop *A* is connected in series with the loop *B* and likewise the loop *D* is connected in series with the loop *C*, Fig. 20. This connection

remains while the armature rotates for one-fourth revolution from that in Fig. 19, when the loops *B* and *D* are short-circuited by the brushes and the loops *A* and *C* are in parallel between the brushes. During this one-fourth revolution the e.m.f. induced in loops *B* and *D* decreased in value from a maximum to zero value, as shown by the curve *bd* in Fig. 21, and the e.m.f. induced in the two loops *A* and *C* has increased in value from zero to a maximum value, as shown by the curve *ac* in Fig. 21. The e.m.f. between the brushes is the sum of the e.m.f.'s and it is represented by the heavy curve in Fig. 21. The maximum value of this e.m.f. occurs when the loops are making an angle of 45 degrees with the position shown in

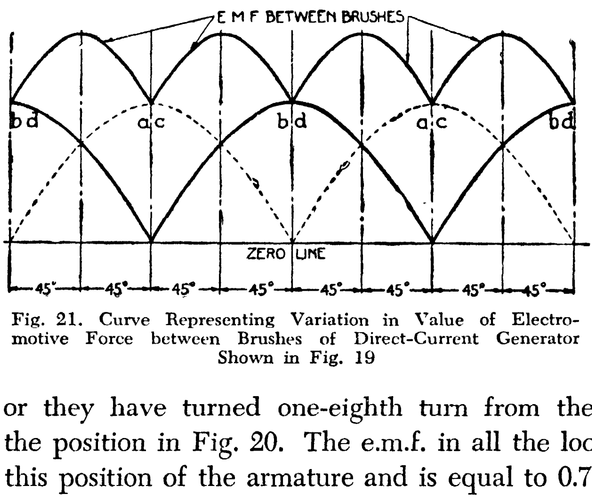


Fig. 21. Curve Representing Variation in Value of Electromotive Force between Brushes of Direct-Current Generator Shown in Fig. 19

Fig. 19, or they have turned one-eighth turn from the starting point, to the position in Fig. 20. The e.m.f. in all the loops is the same for this position of the armature and is equal to 0.707 of the maximum e.m.f. The total e.m.f. between the brushes is equal to twice this value, since two loops are in series, or it is equal to 1.414 times the maximum e.m.f. that can occur in any one of the loops. The e.m.f. between the brushes will fluctuate between the maximum value occurring in a single loop and 1.414 times this maximum value. With a four-loop armature there will be four of these pulsations for each revolution, as shown in Fig. 21. As the number of loops and segments is increased the amount of this fluctuation is decreased (the height of the rise and fall of voltage wave, Fig. 21) but the number of fluctuations per revolution is increased.

In Fig. 22, the number of loops of wire and commutator bars

has been increased from 4 to 8. Conductors *A, B, C,* etc., connect on the rear to similarly lettered conductors *a, b, c,* etc. In order to simplify the drawing these connections are not shown in Fig. 22. Note that the direction of the flow of current in the conductors is indicated by the dot or the plus sign inside the conductor; also the position of the brushes has been shifted to the horizontal center line of the poles. This enables the leads from the coil to the commutator bars to be shorter and more uniform in appearance. The position of the brushes can be changed by moving the leads from the coil to a different commutator bar. In most of the modern direct-current armatures, the coil leads are made about equal in length and the brushes are located in position shown in Fig. 22 in relation to the poles.

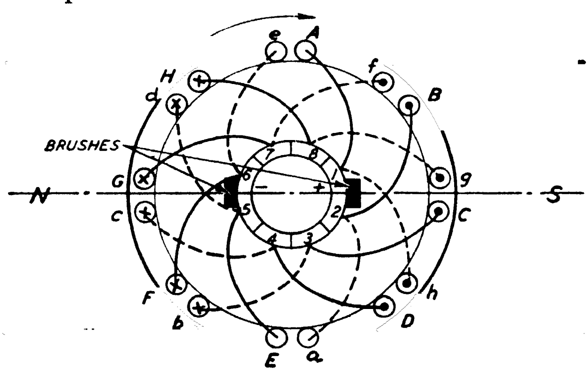


Fig. 22. Diagram of an Armature Having Eight Loops of Wire and Eight Commutator Segments

OPEN- AND CLOSED-CIRCUIT ARMATURE WINDINGS. In an open-circuit winding the different loops do not as a whole form a closed circuit, but each loop is in circuit only when the commutator segments to which it is connected are in electrical contact with the brushes. The windings shown in Figs. 14 and 16 are of the open-circuit type.

A closed-circuit winding is one in which the loops forming the winding are interconnected and form one or more closed circuits upon themselves, and each loop is always in circuit except when it is short-circuited by the brushes. The winding shown in Figs. 19, 20 and 22 is of the closed-circuit type.

Practically all modern armatures are of the closed-circuit type.

Chapter III

Ohm's Law

ELECTRICAL MEASUREMENTS. This brings us down to the point in the study of our electrical circuits where, if we wish to know definitely of these circuits, it is necessary to apply measurements to their separate parts. Perhaps you had not thought of the important part that measurements of any kind play in our economic advancement. Without the establishment of units and the use of these units in measurements and calculations, it would be impossible to build even the simple devices so necessary to our comfort and pleasure. This all applies to articles of furniture, to clothing, to the laying out and to building of roads as well. If these measurements are necessary in things so visible as these, it is equally as necessary with the more or less indefinable subject of electricity.

THREE FACTORS OF THE CIRCUIT. You have seen where the three important factors of the electric circuit are **pressure, current,** and **resistance.** These, however, are general terms and must be broken up into units for accurate handling in measurements. Just as the unit of distance in lineal measurement is the foot, and the unit of physical pressure is the pound, so the unit of electrical pressure is the volt. You, perhaps, could not define these units the foot and the pound (other than by breaking them up into smaller units), nor do you have to know the history of their origin in order to use them in accurate measurements. Nor will it be necessary, as far as the ordinary use in commercial work is concerned, for you to go into the history of this unit of electrical pressure and these other units of current and resistance. It is sufficient, for the present at least, for you to know that:

The **volt** is the **unit** of electrical **pressure.**

The **ampere** is the **unit** of electrical **current.**

The **ohm** is the **unit** of electrical **resistance.**

That these three factors of the circuit—the volt, the ampere, and the ohm—were the key factors to the study of electrical circuits

and their actions, was the conclusion of George Simon Ohm, a German scientist, as he pondered over the question in 1827, and from these conclusions he formulated the all-important **Ohm's Law** which stands today as the basic formula underlying all electrical theory and measurement. The unit of resistance was given his name. This famous Ohm's Law is the simple statement that:

The current in an electric circuit is equal to the pressure divided by the resistance.

This law can also be written in formula form:

$$\textbf{Current} = \frac{\textbf{Pressure}}{\textbf{Resistance}}$$

NOTE: The above formula is read **current** equals **pressure** divided by **resistance.** In a formula when a word, letter, or number is placed above a line and over another word, letter, or number, the line has the same meaning as the sign $\div$, which is read *divided by.*

This is far too unwieldy a form for quick use, and so abbreviations, symbols, or letters are used to represent these words:

$$\begin{aligned} &\textbf{Pressure} &&= \textbf{Volt} &&= \textbf{E} \\ &\textbf{Current} &&= \textbf{Ampere} &&= \textbf{I} \\ &\textbf{Resistance} &&= \textbf{Ohm} &&= \textbf{R} \end{aligned}$$

In explanation: the **E** is the first letter of the term **electromotive force,** which is used in the study of pressure when the units are unknown; the **I** is the first letter of the term **intensity of current** rather than make use of the letter **C,** as the latter is a symbol which has other uses; and the **R** is the first letter of the word **resistance.** Thus, the formula

$$\textbf{Current} = \frac{\textbf{Pressure}}{\textbf{Resistance}} \text{ can now be written } \textbf{I} = \frac{\textbf{E}}{\textbf{R}}$$

This formula, of course, is of use only to find the current when you know the pressure and resistance. The formula can be rearranged so that the letter which stands for what you want to find is on the left side of the equality sign. As there are only three members of this formula, there are just three possible forms of arrangement. They are:

$$\textbf{I} = \frac{\textbf{E}}{\textbf{R}} \quad \textbf{E} = \textbf{IR} \quad \textbf{R} = \frac{\textbf{E}}{\textbf{I}}$$

LEARNING OHM'S LAW. As there are just these three forms of this formula, it is best to learn them as written above. Do not read them hurriedly and pass them by, but learn them thor-

oughly, for they are absolutely necessary to your understanding of the subject. Perhaps a study of them will help fix their relations in your mind.

Since Ohm's law is one of the most commonly used fundamentals of electricity, it is essential that it should be memorized. A very ingenious way of representing and of memorizing Ohm's law is embodied in Figs. 1 to 4. If any one part be removed or covered, the relative position of the other two gives the value of the one covered in terms of the other two.

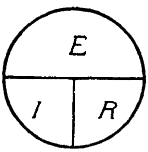


Fig. 1

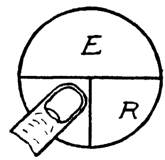


Fig. 2

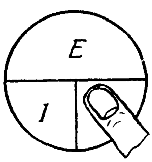


Fig. 3

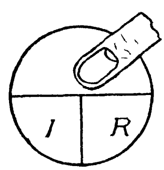


Fig. 4

Thus if we cover I, Fig. 1, $E \div R$ is left, Fig. 2. Therefore the value of I in terms of E and R is E divided by R. If R is covered, $E \div I$ remains, Fig. 3, giving the value of R in terms of E and I, which is E divided by I. In the same way, if we cover E, we have its value remaining in terms of I and R, namely, I times R, Fig. 4.

Example 1

A voltage of 6 volts is used to force a current through a resistance of 3 ohms. What is the current?

Solution

The voltage (E) is 6 volts and the resistance (R) is 3 ohms, we wish to find the current (I). Using the first statement of Ohm's law we find that

$$I = \frac{E}{R} = \frac{6}{3} = 2 \text{ amperes}$$

Example 2

What voltage is required to force a current of 2 amperes through a resistance of 10 ohms?

Solution

The current (I) is 2 amperes and the resistance (R) is 10 ohms. We want to find the voltage (E).

$$E = I \times R = 2 \text{ amperes} \times 10 \text{ ohms} = 20 \text{ volts}$$

Example 3

A voltage of 20 volts is required to force a current of 5 amperes through a coil. What is the resistance of the coil?

Solution

Voltage (E) = 20 volts. Current (I) = 5 amperes

$$R = \frac{E}{I} = \frac{20 \text{ volts}}{5 \text{ amperes}} = 4 \text{ ohms}$$

Example 4

The voltage between the ends of a piece of wire is 15 volts and its resistance is 3 ohms. What current will flow through it?

Solution

Covering the symbol I in the diagram, Fig. 1, there remains $E \div R$. Substituting the values of voltage and resistance given, we have $15 \div 3 = 5$ amperes.

Example 5

A current of 10 amperes is forced through a conductor by a pressure or voltage of 30 volts. What is the resistance of the conductor?

Solution

Covering R in the diagram, Fig. 3, we have left $E \div I$. Substituting for E and I their values from the conditions as stated, we have $30 \div 10 = 3$ ohms.

Example 6

A current of 10 amperes flows through a resistance of 2 ohms. What is the voltage that is forcing the current through the resistance?

Solution

Covering E, Fig. 4, we have left I times R. Substituting their values as before, we have $10 \times 2 = 20$ volts.

APPLICATIONS OF OHM'S LAW. Ohm's law may be applied to a circuit as a whole or it may be applied to any part of the circuit—a circuit being the path through which a current flows from its source through a conductor back to its source. A great amount of caution and practice is required to apply this law correctly in all cases. Accordingly, there is no part of electrical work where so many mistakes are made as in the application of this simple law. Once the principle is firmly grasped, the student is prepared to handle correctly a wide range of electrical problems.

Many of the difficulties will be cleared up if the student will keep in mind the following two statements and will use them intelligently.

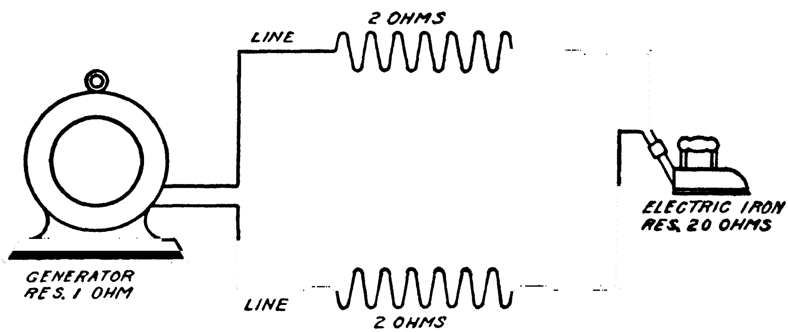


Fig. 5

When applying the law to the *entire* circuit, state the law as follows:

(1) The current in the entire circuit equals the voltage across the entire circuit divided by the resistance of the entire circuit.

Notice that the term "*entire*" applies to current, voltage, and resistance. Not to one of them, but to *all* the factors of the equation.

When applying the law to a part of the circuit, state the law as follows:

(2) The current in a certain part of a circuit equals the voltage across that same part divided by the resistance of that same part.

Notice here again that the values for current, voltage, and resistance are taken from the "*same part*" of the circuit. By far

the greatest number of mistakes in applying Ohm's law come from dividing the voltage across one part of the circuit by the resistance of some other part of the circuit and expecting to get the current in some part of the circuit.

Example 7

Fig. 5 is a diagram of a typical direct-current circuit. The generator has a resistance of 1 ohm and generates 150 volts at no load. Each line wire has a resistance of 2 ohms. The iron which represents the load has a resistance of 20 ohms. What is the current in the circuit?

Solution

The resistance of the entire circuit is the resistance of the generator plus the resistance of the lines plus the resistance of the load, or

$$R = 1 + 2 + 2 + 20 = 25 \text{ ohms}$$

The total voltage produced is 150 volts, therefore the current is

$$I = \frac{E}{R} = \frac{150}{25} = 6 \text{ amperes}$$

IR Drop

The electromotive force of a generator, such as a dynamo or a battery, is the potential difference maintained between its terminals when no current is being taken from it. When current is taken from the generator, the terminal voltage—that is, the voltage applied to the line—is less than the open circuit voltage by an amount equal to the resistance drop or *IR* drop in the generator. The potential difference existing between two points in a circuit is called drop in potential, potential drop, fall of potential, voltage, and the like.

By Ohm's law the voltage drop in any *part* of a circuit is equal to the current in that part multiplied by the resistance of that part of the circuit.

$$E = I \times R \text{ volts}$$

in which E is the voltage, I the current, and R the resistance of *that part* of the circuit.

Thus the fall of potential in that portion of a circuit whose resistance is R is often called the "*IR drop*," as the *IR* drop applies to any *part* of the circuit it will also by proper use apply to the entire circuit.

Example 8

What is the IR drop across the electric iron shown in Fig. 5, when 6 amperes are flowing through it?

Solution IR drop $= 6 \times 20 = 120$ volts

Example 9

In Fig. 5 what is the voltage drop in the line when a current of 6 amperes flows through the circuit?

Solution

The total IR drop in the line will be twice that in one of the wires. The total line drop is

$$IR \text{ drop} = (6 \times 2) \times 2 = 24 \text{ volts}$$

Example 10

What is the IR drop in the generator when it is delivering a current of 6 amperes?

Solution IR drop $= 6 \times 1 = 6$ volts

Example 11

What must be the open circuit voltage of the generator in order that it deliver a current of 6 amperes to this circuit?

Solution

Electromotive force $= 120 + 24 + 6 = 150$ volts

Or, total resistance $= 1 + 2 + 2 + 20 = 25$ ohms

Total IR drop in circuit $= 6 \times 25 = 150$ volts

Suppose that the circuit to the electric iron is opened by removing one of the wires fastened to the electric iron. Then when a voltmeter is connected to the two wires coming from the generator shown in Fig. 5, it will read 150 volts. The voltmeter will also read 150 volts when it is connected to the wire removed from the iron and the wire fastened to the iron. The reason for this is because there is not any current flowing through the circuit, and the voltage between the two wires of the circuit is the same at all points.

Now reconnect the wire back to the electric iron, and the voltmeter will read 120 volts between the two wires connected to the electric iron. (See example 8.) It will read 144 volts (150 less 6 volts drop in generator) at the terminals of the generator. The difference between the voltage at the electric iron and that at the generator is 24 volts (see example 9) which are used up in forcing the current through the line which has a resistance of 4 ohms. Thus the **I R** drop is the voltage used in forcing a current through the circuit to the point where it is made to do useful work.

EMPHASIZING THE IMPORTANCE OF PRESSURE. You have seen how the statement in the formula **E = IR** shows the volts to be the largest and perhaps the most important member of the

formula. You will also remember that the scientist, Ohm, devised this formula to represent the actual relations of the circuit over a long period of tests; and he was so accurate in his assumptions that today, after more than one hundred years, the formula is in universal use without a thought as to its change. As this formula represents the actual relations of the circuit, then it is true that the pressure is the essential factor of the circuit. This is as certainly true in the water or hydraulic systems, to which for the sake of study, the electrical circuits are continually being compared.

In the water system the pipes may be full of water, but none will flow at the faucet unless there is pressure in the water mains. Just so in the electric circuit, there is no current flowing in the circuit unless there is electrical pressure in that circuit.

An electrical generator is simply a device for keeping up pressure in an electrical system. When the generator stops, the pressure is cut off and the current ceases to flow.

From these statements we can see the direct effect upon the current of a circuit is caused by the changing of the circuit's resistance. Any change in the resistance will increase or decrease the total resistance of the circuit which holds back the pressure, and a corresponding change results in the current flowing through the circuit. From this is also gained an idea of the interrelation between pressure and current, and how the volume of the current is directly dependent upon the pressure of the circuit.

Pressure is a factor supplied from an outside source, such as a storage battery; the amount of current is a result of a balance between pressure and resistance; while resistance is a physical part of the circuit and its change is only effected by a physical change in the apparatus.

It is true that no current is lost as it passes through the circuit. If any current flows at all, it flows from the source of power through the entire circuit and back again to the power source. Pressure is the only one of these three factors which suffers a loss, and its value is reduced to zero as the point in its travels through the circuit is reached where it again enters the source of power.

Current can be controlled through a voltage change and this is usually done through the adjusting of a resistance.

POWER EQUATION

The Power Equation is—"The power, in watts, equals the amperes of a circuit $\times$ volts of the circuit," and is written

$$P = IE$$

P standing for watts, I for current, and E for volts.

The equation can be arranged as shown in Fig. 6. Applying the method learned in Ohm's Law by covering up the quantity we want, it becomes evident how to find it. Cover P, Fig. 7, and you have $P = I \times E$. Cover I, Fig. 8, and you have $I = P \div E$. Cover E, Fig. 9, and you have $E = P \div I$.
A study of this will show you that if the voltage of the circuit be doubled, the circuit must be adjusted to halve the current if the

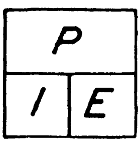


Fig. 6. Power Formula

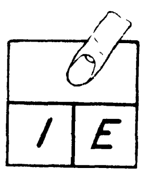


Fig. 7. To Find Power

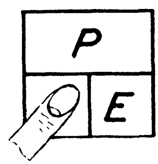


Fig. 8. To Find Current

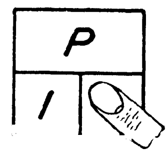


Fig. 9. To Find Voltage

power to be transmitted is to remain the same. This is probably better explained with the use of a small and simple equation. In this way the limitation of voltage values for transmission is clearly shown.

You do not have to stop and think when told that

$$16 = 8 \times 2$$

You also know that the value of 16 is not increased nor decreased but remains the same, when it is written

$$16 = 2 \times 8 \text{ or } 16 = 4 \times 4$$

Now if we have 2 amperes flowing through a circuit with the pressure of 8 volts, we have 16 watts of power in the circuit. We would still have 16 watts if we had 8 amperes at a pressure of 2 volts or 4 amperes at a pressure of 4 volts.

If you were attempting to light four 4-watt lamps, you would know that the wattage of the circuit would necessarily have to be constant. You could not keep this constant if you attempted to raise the line voltage without some different arrangements being made in the circuit to hold back the current or else the wattage

would also rise. So the voltage of the lamps is not chosen until after the circuit voltage is determined, this choice will supply the current-limitation features of the circuit. We are primarily concerned here with the reduction of the line loss or "voltage drop" in the length of the supply lines required to reach the lamps of the circuit, so we will follow this study through in this direction.

Line loss is a loss in pressure, and since this loss in pressure is governed by the amount of current sent through a line, it is to our interest to keep this current down to as small a value as practicable. This can be worked out by a voltage adjustment as you will readily see if you follow carefully the working out of this Power Equation.

We would like to transmit 16 watts to supply our four 4-watt lamps. Since there are no known conductors lacking resistance, it stands to reason that these supply mains must possess some resistance. For the purpose of keeping away from the mathematics of fractions, let us say that this supply line has a resistance (R) of 2 ohms—a value much too high for the successful operation of so small a circuit, as you will soon see. The equation for power lost in supply lines is

$P = I^2 R$ or $P = (I \times I) \times R$ or

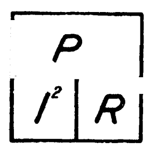


Fig. 10. Power Loss Formula

meaning that the power in watts lost in this line is equal to the amperes of the line *squared* (the quantity multiplied by itself) then multiplied by the resistance of the line in ohms. We would like to transmit 16 watts over this line which has 2 ohms resistance ($2\ R$). Now if we have a line pressure of 8 volts, the current will be 2 amperes, and fitting this to our equation—you see we use the amperes only, not the volts—we have a power loss in the line equal to 2 amperes squared (2×2) which equals 4, and this is multiplied by the 2 ohms line resistance.

$$P = (2 \times 2) \times 2$$
$$P = 4 \times 2 = 8$$

We have then 8 watts lost in line transmission; and since it is lost, it has to be deducted from the 16 watts which we had to transmit. This will leave us only 8 watts to supply our 16-watt load. Clearly we will have to either increase our voltage at the generator or decrease the resistance of our transmission line. We have taken in this example the highest voltage we could use unless we took a voltage of 16 and a current of 1 ampere. Let us continue with this equation $P = I^2 R$ and follow it through with 16 volts and 1 ampere. The 1 ampere squared (1×1) would give us a figure of 1 and this multiplied by the 2 ohm resistance of the line would give us a power loss of 2 watts.

$$P = (1 \times 1) \times 2$$
$$P = 1 \times 2$$
$$P = 2 \text{ watts}$$

This would leave us $16 - 2$ or 14 watts to power our lights. We clearly would have to reduce our line resistance to get a smaller loss or else still further increase our voltage. We could do both of these, but even then we could not expect to deliver all the generated wattage to the lamps for some line losses will always exist.

Diesel Locomotive and Interior of Engineer's Cab

Chapter IV

Electrical Power Measurements

WORK AND POWER. The words **work** and **power** are often confused or interchanged in common use. The proper use of the term **work** means the overcoming of resistance. **Power** means the speed or rate of doing work.

$$\text{Work} = \text{Force} \times \text{Distance}$$

When a force acts upon a body, the product of the force multiplied by the distance through which it acts in the direction of the force is called the work performed by the force. Thus, when a force applied to a heavy body raises it a vertical distance, work is performed by the force. The amount of work is the product of the force and the distance of ascent. In other words, **work** is the result obtained by multiplying the force it takes to pull a bucket of water upward by the distance the bucket was raised.

Force is generally measured in pounds and distance is in feet, so when the two are multiplied together, as explained above, the result is foot pounds. Therefore, the term **foot pound** is the measure of work.

Fig. 1 shows a man carrying a bucket of water weighing 20 pounds up a flight of stairs to a platform 10 feet high. The force required to lift the bucket of water is 20 pounds, and the vertical distance it has been raised is 10 feet. The force required to lift a load or weight of any kind is always equal to the load. If an object weighs 20 pounds, then 20 pounds of force is required to lift it. The quantity of **work** the man has done is the product of the force and the distance upward, or 20 pounds multiplied by 10 feet, which equals 200 foot pounds. In formula form this is written as follows:

$$\text{Work} = 20 \times 10 = 200 \text{ foot pounds}$$

Fig. 2 represents a man raising a bucket of water weighing 20 pounds, to a platform 10 feet above the level upon which he is standing, by means of a rope and pulley. Here again the force is 20 pounds and the vertical distance is 10 feet. The **work** performed

is still force times distance, or $20 \times 10 = 200$ foot pounds. The 20 represents the force and the 10 the distance, as in above.

Suppose, instead of lifting the water by manual effort, it is forced up to the bucket by a pump driven by a motor, as shown in Fig. 3. In order to fill the bucket, which is placed upon the platform 10 feet above the level of the water tank, 20 pounds of

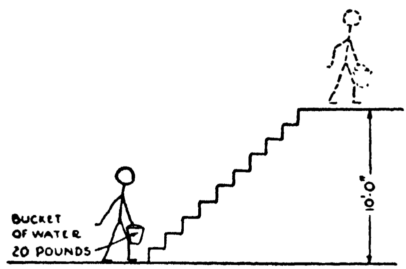


Fig. 1. Man Carrying a Bucket of Water Up a Vertical Distance

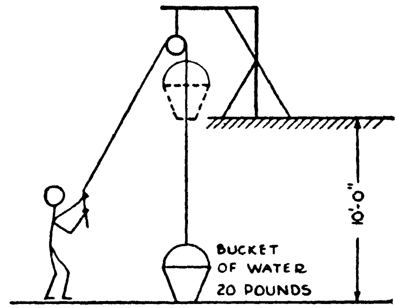


Fig. 2. Raising a Bucket of Water by Means of a Rope and Pulley

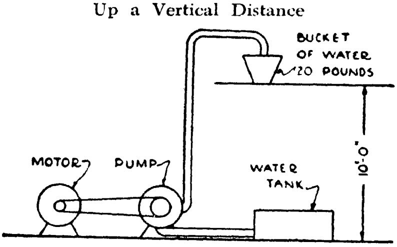


Fig. 3. Pumping Water by Means of a Motor Driven Pump

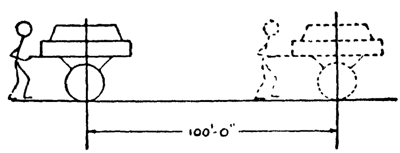


Fig. 4. Man Pushing a Cart in Which Resistance to Motion Is Twenty Pounds

water are required. Therefore, the motor must do 200 foot pounds of **work.** Here the motor does the work done by the man in Figs. 1 and 2. When a horizontal force moves a body horizontally, the **work** is the product of the force and the horizontal distance. As an example of this, take the ordinary street car in which motors are used to push the car along the street.

Fig. 4 shows a man pushing a cart. To keep the cart moving at a constant speed, it is necessary that the man apply a force of 20 pounds to overcome the friction or resistance to motion. Therefore, when he has pushed the cart 100 feet, he has performed an amount of work equal to force times distance, or

$$20 \times 100 = 2000 \text{ foot pounds}$$

In any of the above cases no mention of time has been made. The amount of **work** done is the same whether the task has been performed in one minute or one hour.

POWER. In the formula for calculating **power,** it is necessary to divide the force times the distance (in other words, the **work**) by the time taken to do the work.

$$\text{Power} = \frac{\text{Force} \times \text{Distance}}{\text{Time}} = \frac{\text{Work}}{\text{Time}}$$

Power means the speed or rate of doing work. The faster **work** is done, the greater the **power** required to do it. Fig. 3 shows a motor-driven pump raising water from a tank to a platform 10 feet above it. To deliver 20 pounds of water, it will take 200 foot pounds of work. In order to deliver this water at the rate of 20 pounds per second to a height of 10 feet, the power required is $\frac{20 \times 10}{1} = 200$ foot pounds per second, or $200 \times 60 = 12{,}000$ foot pounds per minute. First, we found the **power** required per second to lift 20 pounds of water in a second by dividing the **work** by **one second.** Then we found the foot pounds per minute by multiplying 200 by the number of seconds in a minute. Suppose the man shown in Fig. 4 pushes the cart 100 feet in six seconds. The power required is **work** done divided by the time, or $\frac{20 \times 100}{6} = 333\frac{1}{3}$ foot pounds per second.

Study the above explanations very carefully until you are sure you understand them and will remember them.

HORSEPOWER. The earliest use of steam engines was to pump water from mines. This work had previously been done by horses, consequently, the power of the various engines was estimated as equal to that of so many horses. Finally, James Watt carried out some experiments to determine how many foot pounds of work a horse could do in one minute. He found that a strong dray horse working for a short time could do work at the rate of 33,000 foot pounds per minute. This rate is therefore called horsepower. To determine the horsepower of a machine, compute the number of foot pounds of work per minute and then divide by 33,000.

$$\text{Horsepower} = \frac{\text{foot pounds per minute}}{33{,}000}$$

Referring to Fig. 3, the horsepower required to raise 20 pounds of water 10 feet in one second is

$$\text{Horsepower} = \overset{(A)}{\frac{\text{pounds per minute} \times \text{height}}{33{,}000}} = \overset{(B)}{\frac{\text{foot pounds per minute}}{33{,}000}} = \overset{(C)}{\frac{12{,}000}{33{,}000}} = 0.36$$

The first part (A) of this horsepower formula refers to the explanation for finding **power.** If 20 pounds of water must be lifted per second, then in 60 seconds (one minute) $20 \times 60 = 1200$ pounds of water would be lifted. We must always base our calculations on minutes, because the horsepower formula is based on minutes. Now if we multiply 1200 by 10 (the distance), we get 12,000 foot pounds, which is the power. Thus the formula at (A) could be written

$$\text{Horsepower} = \frac{12{,}000}{33{,}000}$$

The second part (B) of the horsepower formula means the same as the part at (A). The only difference is in the wording, because pounds per minute times height gives foot pounds per minute. So (B) could be written.

$$\text{Horsepower} = \frac{12{,}000}{33{,}000}$$

In the third part (C) of the horsepower formula, we have used the numerical value of pounds per minute times height and foot pounds per minute. Then 12,000 is divided by 33,000 and the answer is as shown. These three steps show how the horsepower formula is developed and should be very carefully studied.

The horsepower required to push the cart, Fig. 4, a distance of 100 feet in 6 seconds, that is, to do 20,000 (see explanation on page 49) foot pounds work per minute, is

$$\text{Horsepower} = \frac{\text{foot pounds per minute}}{33{,}000} = \frac{20{,}000}{33{,}000} = 0.6$$

ELECTRIC POWER. To measure waterpower, we must know the quantity of water flowing by a given point per minute and the head (which means height) to which it is raised.

$$\text{Waterpower} = \text{quantity of water per minute} \times \text{head}$$

$$\text{Horsepower} = \frac{\text{pounds per minute} \times \text{head}}{33{,}000}$$

To measure electric power, we must multiply the quantity of electricity flowing per second, that is, the current in amperes, by the voltage.

$$\text{Electric power} = \text{Amperes} \times \text{Volts}$$

In the problem illustrated by Fig. 3, it was stated that 20 pounds of water was being delivered to the platform in one second. Thus we speak of the water as flowing at the rate of 20 pounds per second. In much the same way we speak of electricity as flowing along a wire at the rate of so many **coulombs** per second. The coulomb is the unit of quantity of electricity, just as the gallon is the unit of quantity of water. We have to consider the rate of flow of electricity so often that we have a special name for the unit of rate of flow (one coulomb per second). We call it an **ampere.** Thus 5 amperes means 5 coulombs per second.

The **watt** is the unit of electric power and may be defined as the power required to keep a current of one ampere flowing under a drop or head of one volt. For example, if a lamp draws 0.5 amperes from a 110-volt circuit, it is using power at the rate of $0.5 \times 110 = 55$ watts. Since the watt is a very small unit of power, we commonly use the kilowatt (Kw.), which is 1000 watts.

$$\text{Kilowatt} = \frac{\text{Amperes} \times \text{Volts}}{1000}$$

Inasmuch as mechanical power is reckoned in horsepower, it will be convenient to know the relation of the unit of mechanical power to the unit of electrical power. Experiment shows that

$$\begin{aligned} 1 \text{ horsepower} &= 746 \text{ watts} \\ 1 \text{ kilowatt} &= 1.34 \text{ horsepower} \end{aligned}$$

DIRECT-CURRENT POWER MEASUREMENTS

VOLT-AMMETER METHOD. In direct-current circuits, power is equal to the product of the volts applied to the load times the current in amperes passing through the load.

$$\text{Power} = \text{Volts} \times \text{Amperes}$$

It is therefore the usual practice to measure direct-current power by means of a voltmeter and an ammeter, it only being necessary to multiply the volts by the amperes to obtain the power in watts. Particular care must be taken that they are the true values as stated

above, namely, the volts applied to the load and the current in amperes passing through the load. To obtain these values certain precautions are necessary. Should the meters be connected as shown in Fig. 5 or in Fig. 6? The voltmeter, connected as shown in Fig. 5, measures the true volts applied to the load but the ammeter reads the sum of the current taken by the load and that pass-

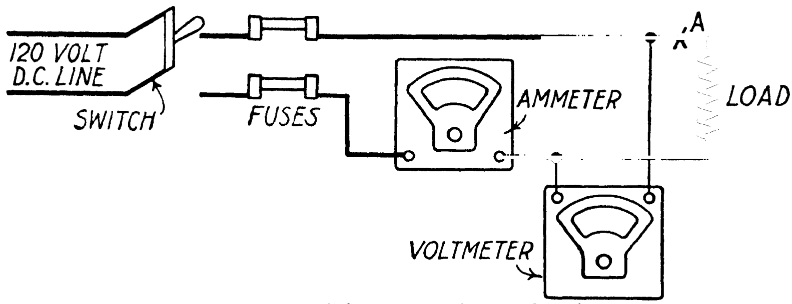


Fig. 5. The Best Method of Connecting Meters When Current Is Large

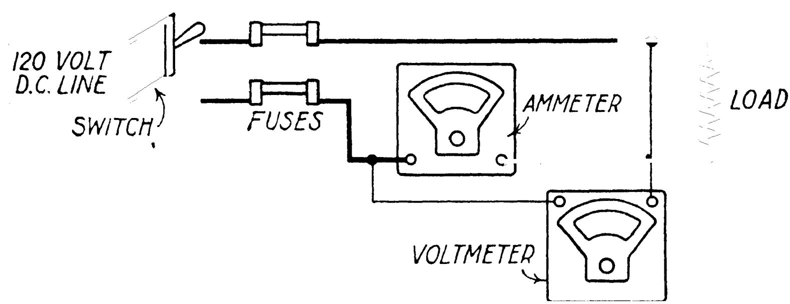


Fig. 6. The Best Method of Connecting Meters When Current Is Very Small

ing through the voltmeter. When connections are made, as shown in Fig. 6, the ammeter indicates the exact amount of current passing through the load but the voltmeter indicates the sum of the voltage drop across the lamp and the voltage drop across the ammeter.

Power calculated from the indications obtained with connections as in Fig. 5 would indicate the watts delivered to the load plus the watts dissipated in the voltmeter. If the voltmeter resistance is known, its wattage may be calculated by dividing the voltage squared (multiplied by itself) by the resistance.

$$\text{Voltmeter Watts} = \frac{\text{Volts} \times \text{Volts}}{\text{Ohms}}$$

If the voltmeter resistance is not known, it may be measured by connecting the voltmeter in series with a low range ammeter and applying the line voltage. The resistance is then calculated by Ohm's Law, from the current indicated by the low range ammeter and the voltage indicated by the voltmeter. A quick check to determine whether or not it is necessary to deduct the watt loss in the voltmeter is to open the load circuit at point A, Fig. 5, and note the ammeter reading. If the deflection is too small to be read, then the watts loss in the voltmeter is small compared to the watts

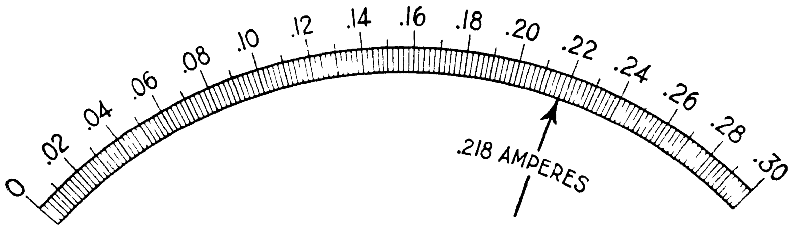


Fig 7 Ammeter Scale

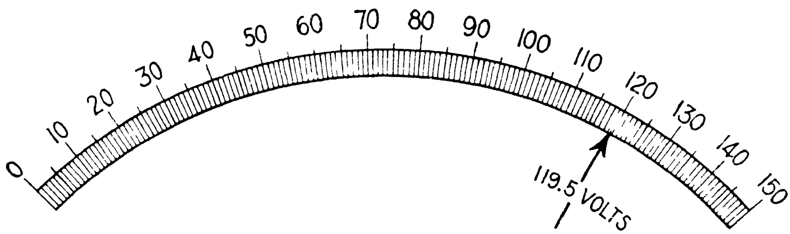


Fig. 8. Voltmeter Scale

taken by the load and may be neglected. This is the most accurate method of measuring direct-current power when corrections are to be made for power lost in the instruments.

When approximate measurements are desired of low voltage loads (100 watts or under), the connections as shown in Fig. 6 are convenient. In this case the watt loss in the ammeter is so small it is usually neglected. However, when measurements are taken for loads carrying larger currents, the losses in the ammeter shunt and connections may become great enough to introduce an appreciable error in the results.

Let us assume that we desire to measure the wattage of a 25-watt incandescent lamp and that the instruments are connected as

shown in Fig. 5. The instruments used are 0.300-ampere ammeter having a resistance of 0.17 ohms and a 150-volt voltmeter having a resistance of 15,000 ohms. The ammeter scale shown in Fig. 7 indicates 0.218 ampere. The voltmeter scale shown in Fig. 8 indicates 119.5 volts.

$$\begin{aligned}
\text{Apparent Power} &= \text{Volts} \times \text{Amperes} \\
&= 119.5 \times 0.218 = 26.05 \text{ Watts} \\
\text{Voltmeter Watts} &= \frac{\text{Volts} \times \text{Volts}}{\text{Ohms}} \\
&= \frac{119.5 \times 119.5}{15{,}000} = 0.95 \text{ Watts} \\
\text{True Watts} &= 26.05 - 0.95 = 25.10 \text{ Watts} \\
\text{Per cent error} &= \frac{0.95}{25.10} \times 100 = 3.78\%
\end{aligned}$$

Since the ammeter has a resistance of 0.17 ohm and is carrying 0.218 amperes, the voltage drop across it is, by Ohm's Law,

$$\begin{aligned}
\text{Volts} &= \text{Amperes} \times \text{Ohms} \\
&= 0.218 \times 0.17 = .037 \text{ volt}
\end{aligned}$$

The true line voltage is then the sum of the voltage across the load plus the drop across the ammeter.

$$\begin{aligned}
\text{Line Volts} &= \text{Load Volts} + \text{Drop across Ammeter} \\
&= 119.5 + .037 = 119.537 \text{ volts}
\end{aligned}$$

On the scale illustrated in Fig. 8, it is practical to read only to the nearest half of a scale division which is 0.5 volt. Therefore, with the instruments connected as shown in Fig. 6 and the same line voltage as in Fig. 5, the voltmeter would still indicate a reading of 119.5 volts. However, we will use the calculated figure given above in order to work out the error in this method of measurement.

If the voltmeter be connected outside the ammeter, as shown in Fig. 6, the ammeter will read the true current passing through the lamp. This current will be equal to the ammeter reading for Fig. 5 less the current passing through the voltmeter.

$$\begin{aligned}
\text{Voltmeter Current} &= \frac{\text{Volts}}{\text{Ohms}} \\
&= \frac{119.5}{15{,}000} = .008 \text{ ampere almost}
\end{aligned}$$

Current passing through the lamp is then

$$0.218 - 0.008 = 0.210 \text{ ampere}$$

$$\text{Apparent Power} = \text{Volts} \times \text{Amperes}$$
$$= 119.537 \times .210 = 25.102$$

Since the true wattage is 25.10 watts

$$\text{Error} = 25.102 - 25.10 = .002 \text{ watts}$$

$$\text{Per cent error} = \frac{.002}{25.10} \times 100 = .008\%$$

The error is so small as to be negligible.

When tests are made on larger loads requiring several thousand watts, the loss in the voltmeter becomes so small in comparison to the amount of power measured that it is negligible. However, the losses in the leads and connections between the point where it is convenient to connect the ammeter and the load to be measured become an important factor which must either be accounted for or eliminated from the calculations altogether.

The exact amount of losses in the leads and connections is difficult to determine, since they consist of not only the ohmic resistance of the conductors and shunt but also include the losses due to contact resistance whenever there are joints. Because contact resistance is a variable and not easily measured quantity, precautions should be taken in testing to eliminate its effect as much as possible.

When small currents are to be measured, the error due to contact resistance is small and, when care is taken in making connections, will have very little effect on the meter indications. But when the currents are large, the contact losses become an appreciable amount of the power to be measured and, for accurate work, measurements must be so taken as to eliminate this error.

Fig. 9 shows the necessary connections for measuring the power delivered to a 20-horsepower 230-volt direct-current motor operating at almost full load. The purpose of this test is to determine whether or not the motor is overloaded. In order to demonstrate the error due to the two methods of connecting in the voltmeter, both connections are shown and values of resistance have been assumed for the resistance due to the leads and contacts.

In the plus lead, the resistance of connections from the motor

to the point *A* at which the voltmeter is connected we will assume is 0.02 ohm, and the resistance of the negative lead including the shunt and connections is 0.025 ohms from the motor to the point *B*. The ammeter indicates 62.5 amperes and voltmeter No. 1 indicates 225 volts. *Voltmeter No. 1 is connected directly to the motor terminals and therefore indicates the true voltage applied to the*

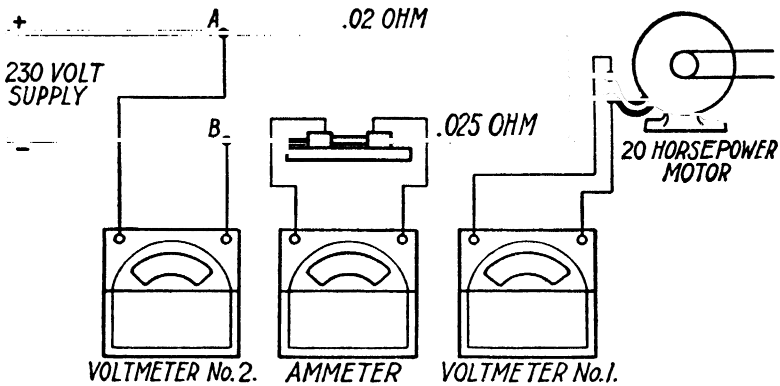


Fig. 9. Necessary Connections for Measuring Power Delivered to a 20-Horsepower D.C. Motor

motor. The ammeter indicates the sum of the current taken by the motor plus that taken by the voltmeter.

$$\text{Apparent Power} = \text{Volts} \times \text{Amperes}$$
$$= 225 \times 62.5 = 14{,}062.5 \text{ watts.}$$

The resistance of the voltmeter is 30,000 ohms

$$\text{Voltmeter No. 1 Loss} = \frac{\text{Volts} \times \text{Volts}}{\text{Ohms}}$$
$$= \frac{225 \times 225}{30{,}000} = 1.69 \text{ watts}$$
$$\text{True Watts} = \text{Apparent Watts} - \text{Losses}$$
$$= 14{,}062.5 - 1.69 = 14{,}060.8 \text{ watts}$$
$$\text{Per cent error} = \frac{\text{Losses}}{\text{True Watts}}$$
$$= \frac{1.69}{14{,}060.8} \times 100 = 0.012\%$$

The error is so small that it is negligible.

Now let us consider the indications resulting if the readings are taken with the voltmeter connected on the line side of the ammeter as represented by voltmeter No. 2.

The total line resistance between the points *A* and *B* and the motor *is*

$$0.025 + 0.02 = 0.045 \text{ ohm}$$

$$\text{Voltage Drop in Line} = \text{Amperes} \times \text{Ohms}$$
$$= 62.5 \times 0.045 = 2.81 \text{ volts}$$

Therefore the line voltage indicated by voltmeter No. 2 is

$$\text{Line Voltage} = 225 + 2.81 = 227.81 \text{ volts}$$

The current taken by voltmeter No. 1 is

$$\text{Current} = \frac{\text{Volts}}{\text{Ohms}}$$
$$= \frac{225}{30{,}000} = 0.0075 \text{ amperes}$$

As this is much too small an amount to be read on the scale of the ammeter, the indication will still be 62.5 amperes.

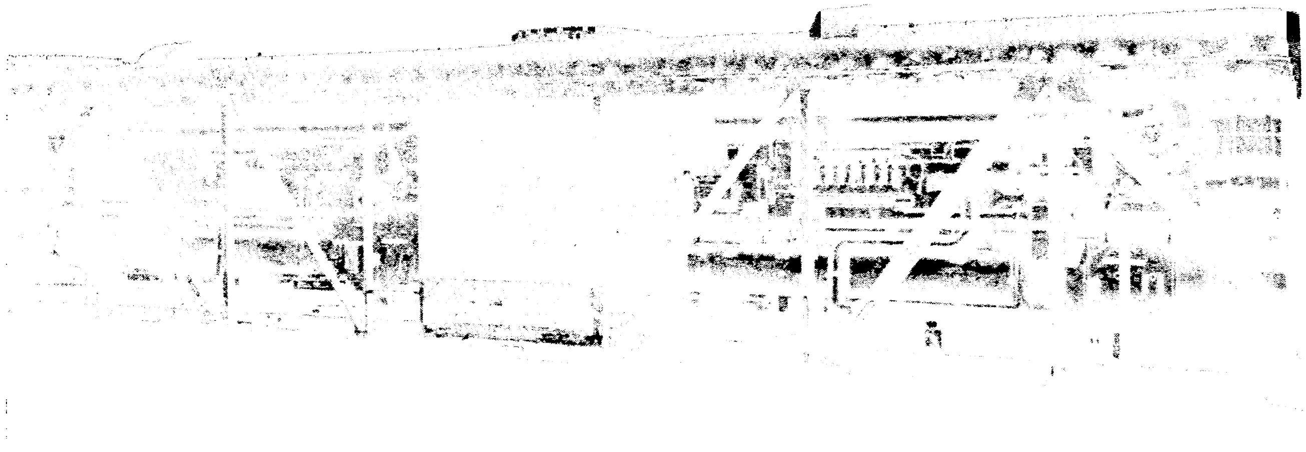
$$\text{Apparent Wattage} = \text{Volts} \times \text{Amperes}$$
$$= 227.81 \times 62.5 = 14{,}238.1 \text{ watts}$$
$$\text{Error} = \text{Apparent Wattage} - \text{True Wattage}$$
$$= 14{,}238.1 - 14{,}062.5 = 175.6 \text{ watts}$$
$$\text{Per cent error} = \frac{\text{Losses}}{\text{True Watts}} \times 100$$
$$= \frac{175.6}{14{,}062.5} \times 100 = 1.25\%$$

While this error is small, it is uncertain and difficult to measure, therefore, the results obtained from the indications of the ammeter and voltmeter No. 1 are to be preferred.

The watts indicated may now be converted into horsepower by dividing by 746, since 746 watts is equal to one horsepower.

$$\text{Horsepower} = \frac{\text{Watts}}{746}$$
$$= \frac{14{,}062.5}{746} = 18.9$$

The motor is therefore not overloaded, since it is rated at 20 horsepower.



Construction of Alco 2000 Horsepower Units

Chapter V

Transmission Equipment

MAIN GENERATORS. The standard construction of the larger capacity railway generators includes a rolled steel frame (some of the smaller machines have cast steel frames) built of

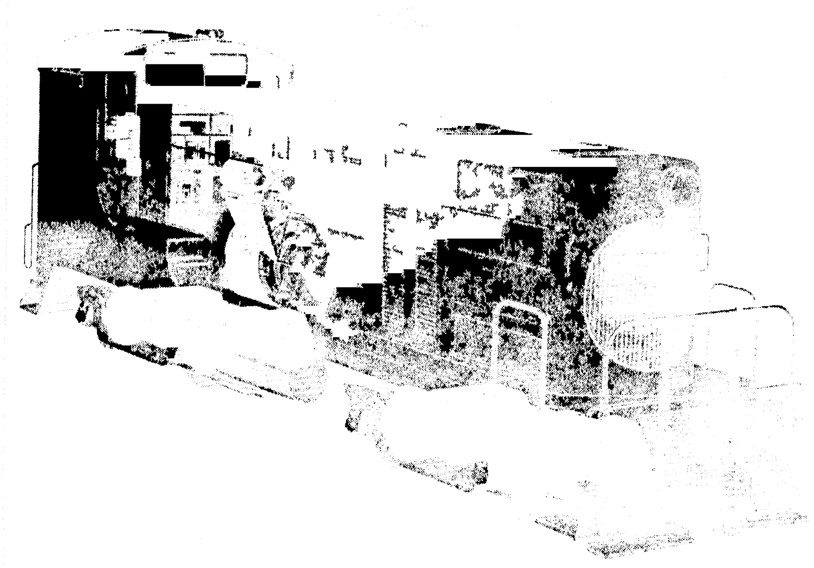


Fig 1. Phantom View of Locomotive Showing Electrical Equipment in Black

ample section for the mechanical and magnetic duties to which it is subjected. Feet or flanges are welded to this frame for supporting purposes. The inside of this rolled frame is then machined to insure an accurate seat for the pole pieces (usually eight main pole pieces in the larger sizes and four for the smaller capacities). A rigid end bracket is provided which bolts to the end of the frame ring and carries the brush holders and the anti-friction bearing supporting one end of the generator armature. (See Figs. 2 and 3.)

The main pole pieces are of laminated steel carefully riveted

together and held to the frame by tap bolts or studs through the frame. The field coils are impregnated and baked with insulating

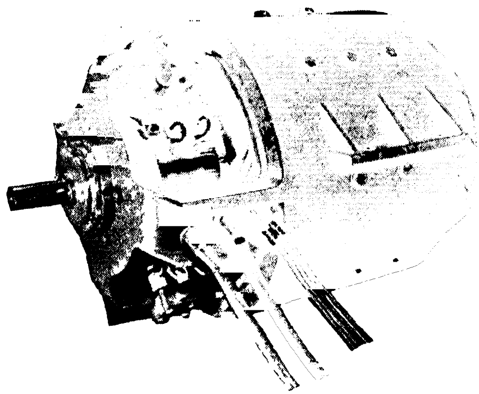


Fig. 2. Westinghouse Rolled Steel Frame Generator for 150 hp. 1800 r.p.m. Diesel Engine

Fig. 3. Roller Bearing Location and Assembly

compounds to guard against movement and chafing within the coil and to permit free flow of the internally developed heat to the surfaces.

The armature is a solid structure, as shown in Fig. 4, carefully built to withstand high speed and all of the vibrations (lateral and torsional) incurred in operating with a Diesel engine. It is dynamically balanced both before and after winding to reduce vibration, and it is supported at one end by the anti-friction bearing and at the other end by the engine crankshaft. Construction is such as to provide adequate ventilation without allowing pockets for the accumulation of dirt and moisture. A fan mounted on the rear of the spider is balanced before assembly on the armature and it is

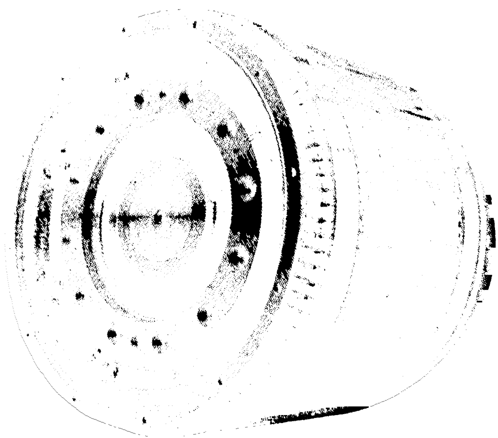


Fig. 4. Complete Generator Armature

arranged to draw air from the commutator end of the generator both through the armature core and air gap, also past the field coils, for removing the heat released in the generator windings and magnetic structure. (See Fig. 5.) The laminated steel armature core and the commutator are each mounted on its individual spider (the commutator spider being fastened to the armature spider) so that a shaft may be replaced without disturbing the armature, or a commutator may be removed without moving the steel core. In the smaller sizes of machines the armature spider is sometimes omitted to reduce the machine size, but the construction is still such that the shaft may be replaced without disturbing the assembly.

Armature coils are form-wound, insulated, and pressed to size during their manufacture, to insure close fits. The armature is

wound with these coils, heated, and then temporary bands are applied, using maple or steel strips in the top of each slot to press the coils solidly into place under the pressure of these temporary bands. The coil leads are then soldered to the commutator bars and the armature again heated, then dipped in an impregnating compound and baked. This insulating compound holds the coils firmly in place, allowing the temporary bands to be removed and the

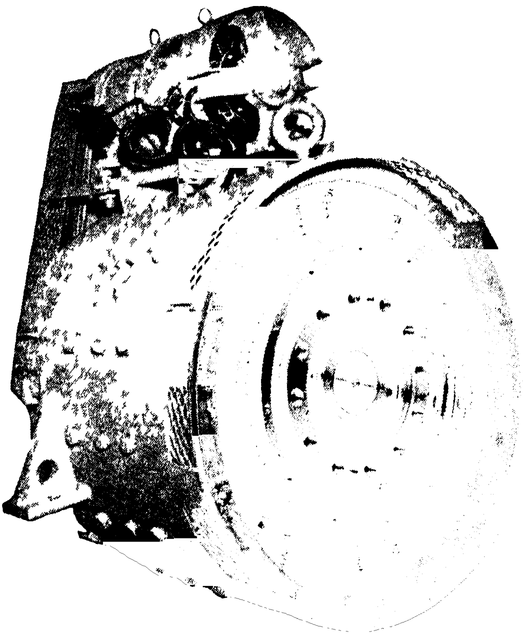


Fig 5. Rear View of a Diesel Electric Generator

wedges and permanent bands to be applied. Another reheating and a final dip and bake precede the final check of the commutator for solidity and smoothness and the final dynamic balancing.

The method of holding the armature coils in place has an important bearing on the generator efficiency. Where steel bands were formerly used to hold the coils in the armature slots, Micarta wedges are now driven into grooves near the top of the slots, thus removing the necessity of having band wire in the vicinity of the armature core. The end windings are banded down solidly by non-magnetic band wire under controlled tension, as shown in Fig. 6. By

the removal of these bands from the magnetic path, eddy current losses are reduced and the danger of loosening the band wire is minimized.

The insulation of the armature and field coils of a Diesel electric generator is Class B, which includes glass, asbestos, and mica. The American Institute of Electrical Engineers has determined that machines with this class of insulation are suitable to operate continuously with a temperature rise of 120° Centigrade for the armature

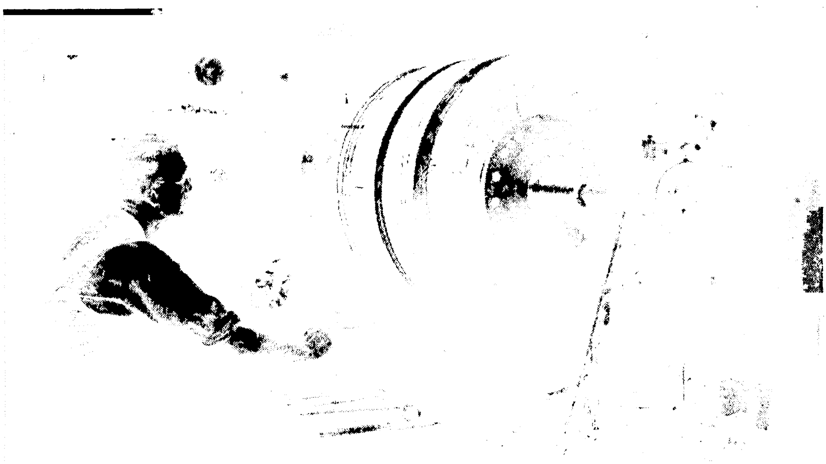


Fig 6 Applying the Permanent Non-Magnetic Bands to an Armature Under Controlled Tension

and 130° Centigrade for the fields, corresponding to 248° and 266° Fahrenheit. Thus, for a day on which the thermometer registers 100° Fahrenheit, it is perfectly safe to operate these machines at a maximum internal temperature of 348° F. in the armature and 366° F. in the fields.

TRACTION MOTORS. In the past, Westinghouse has constructed most of its Diesel electric traction motors with a box type cast frame. Some of the motors for narrow gauge have been built with a split frame so that an armature could be removed without taking the whole motor out of the locomotive or railcar, but the box frame construction is so much more satisfactory that its use is almost universal. While some of the recent high-speed motors

(using multiple gear reductions) have rolled steel frames, a recent development by Westinghouse is an axle hung traction motor whose frame is welded from standard steel plates and shapes, resulting in a powerful motor whose magnetic paths may be more closely predetermined and which is stronger structurally than the cast frame motor. (See Fig. 7.)

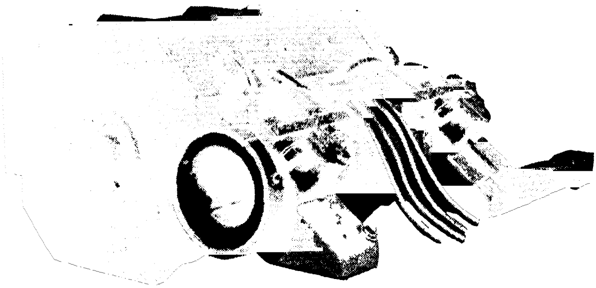


Fig 7. Westinghouse Type 362-B Traction Motor Having a Welded Steel Frame

Fig 8 Relief-Bored Axle Bearing

Internally the welded frame motor embodies the latest features, including Class B insulation throughout, as used in all modern high efficiency traction motors. The main and commutating pole pieces are bolted to machined seats in the frame by tap bolts or studs through the frame, these being sealed against the entrance of water. The pinion end housing is cast (because a casting is more practical for this detail) while the commutator end housing is fabricated.

These carry ample sized roller bearings for supporting the armature. Each axle bearing is of the split type to facilitate the removal of a motor from an axle and is constructed with a bronze shell, relief-bored at the ends to insure ample lubrication for the end thrust

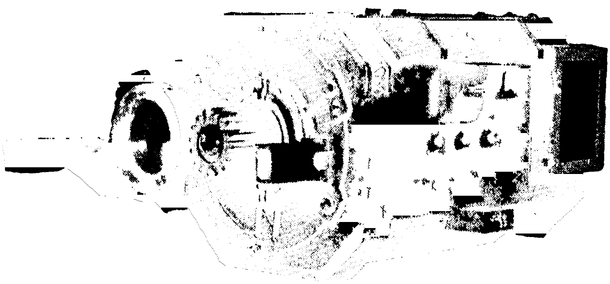


Fig 9. Rear of Type 362-B Traction Motor Showing Double Nose Supporting Lugs

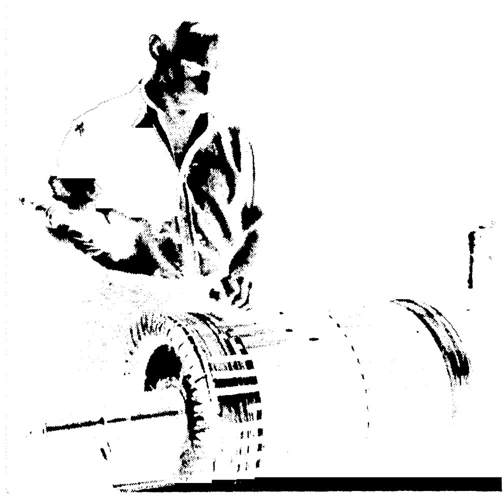


Fig 10 Wedging a Traction Motor Armature

flange and to allow the bearing to seat itself properly. (See Fig. 8.) Each axle cap is held in place by two through-bolts and two tap bolts of high grade steel. A bolted-on axle dust guard prevents the ready entrance of dust and dirt from the roadbed. One brush holder per main pole is provided. Wiring "out of frame" is carefully roped and cleated to minimize vibration and thus prevent chafing.

The support of the motor opposite the axle is spring cushioned against shock for either direction of motion by a double nose suspension arrangement. Fig. 9 shows the upper and lower supporting lugs.

Each main pole piece is constructed of laminated steel, rigidly riveted, and carries a series field coil. The series field coils and the

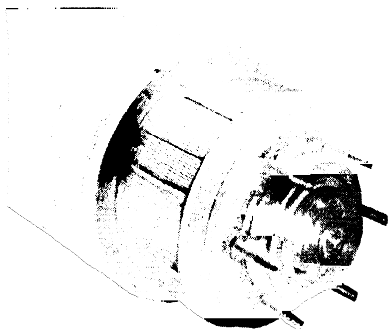


Fig. 11. A Completed Traction Motor Armature

Fig. 12. Gearing for Traction Motor

commutating field coils are impregnated with an insulating compound and baked, to insure rigidity and to facilitate the flow of internally generated heat to the coil surfaces. A spring washer against each coil insures a firm field structure.

The armature is of spider construction so that a shaft or a commutator may be removed without disturbing other portions of the assembly. In other respects it is also similar to the armature of the main generator. (See Figs. 10 and 11.)

Spur gearing is used between the armature shaft and the axle, this being of forged steel treated by the Westinghouse B. P. process for additional strength and long life. (See Fig. 12.)

AUXILIARY GENERATORS. These machines are of conventional Westinghouse railway design, insulated throughout with Class B insulation and embodying the same care of manufacture which characterizes the main generator and the traction motors. When the auxiliary generator is of small size (due to mechanical drive of the fans and compressor) this machine is usually mounted in a common frame with the exciter (Fig. 13), the two armatures being on the same shaft supported by two antifriction bearings. When the

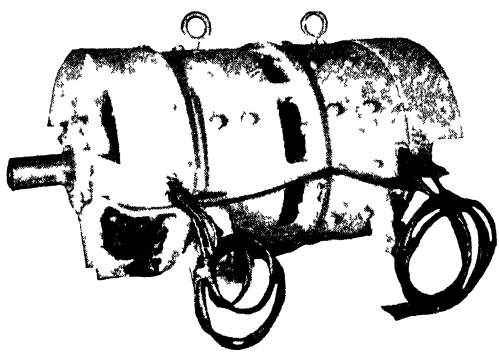


Fig. 13. Combination Auxiliary Generator-Exciter Set Arranged for Belt Drive for Switching and Some Road Locomotives

electrical drive of the compressor and fans is employed, the auxiliary generator is considerably larger and is usually driven directly by the engine (See Fig. 14), the armature being overhung on an extension of the main generator shaft without bearings and the frame supported by the main generator end housing. A two-bearing exciter is then driven from the end of the auxiliary generator shaft extension through a flexible coupling.

DIFFERENTIAL FIELD EXCITERS. The first automatic system of control involved the use of a differential field winding included as a part of the main generator field winding so that, as the current being delivered by the generator to the traction motors increased, the voltage of the generator would decrease. While this system was very simple, the addition of such a differential winding to the main generator fields increased the size of the main generator

very materially. In addition, the characteristic which resulted from the use of such differential winding did not meet the requirements. Fig. 15 shows the shape which the performance curve of a Diesel

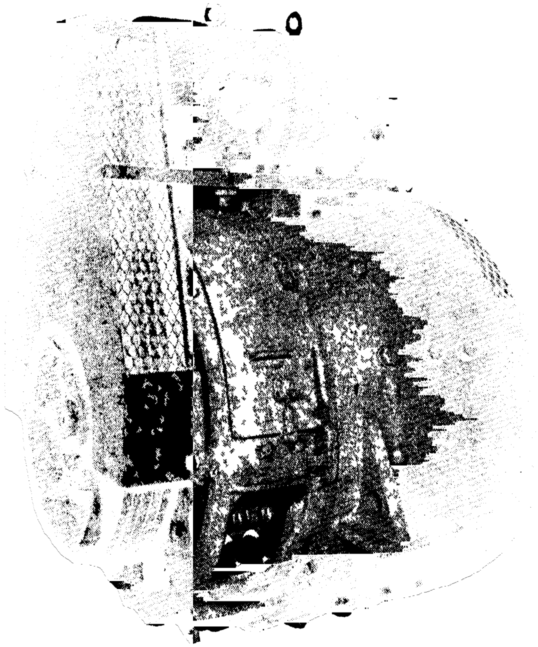


Fig. 14. Direct Driven Main Generator with Belted Auxiliary Generator and Exciter for Road Locomotives

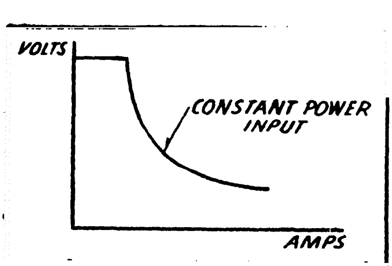


Fig. 15. Fundamental Characteristic Curve of Diesel Electric Motive Power

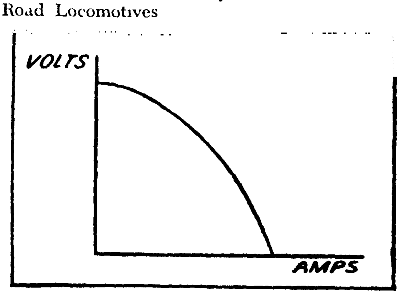


Fig. 16. Usual Differential Field Characteristic

Electric generator should take, while Fig. 16 shows the characteristic of a generator with a differential field winding. Since the one is a concave curve and the other a convex curve, it is obvious that, if one is superimposed over the other, the engine may be seriously

overloaded over a considerable range of train speed, or if the convex curve is shifted downward the engine may be under loaded over a wide range. The net result was that, where this overloading occurred, the engine speed would necessarily drop and thus reduce its output. Fig. 17 shows the net performance curve by the use of such a straight differential field.

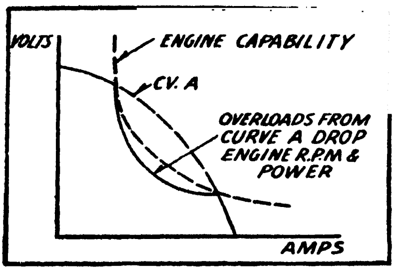


Fig. 17. Overloading and Engine Speed Drop When Usual Differential Field Is Used

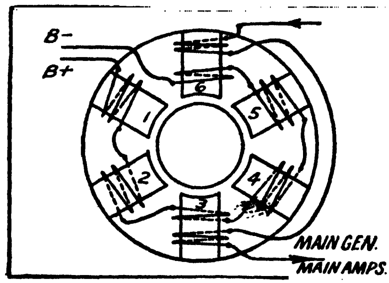


Fig. 18. Westinghouse Differential Exciter Field Arrangement

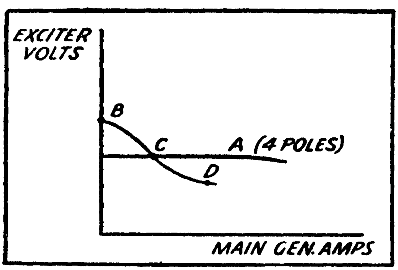


Fig. 19. Early Westinghouse Diesel Exciter Characteristic Curve

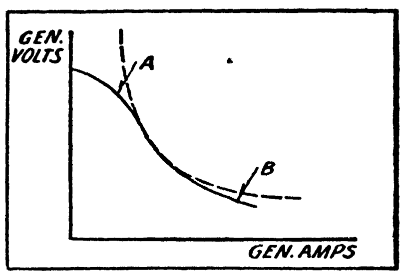


Fig. 20. Early Westinghouse Main Generator Characteristic

An early study of this problem resulted in a scheme which was very practical and which gave much better engine loading characteristics than any other differential control or exciter scheme devised previously. Since any differential field increases the size of the generator to which it is applied, it was arranged to place this winding on the exciter rather than the main generator, thus making this increase in generator size apply to the smaller machine only. By distributing this winding on but two poles of a six-pole exciter, as shown by Fig. 18, the voltage generated by the four other poles is approximately constant at a fixed speed, as shown by A of Fig. 19. The two poles, which carry both a separately excited winding and

a main generator amperes differential series field coil, are reduced in magnetic section so that they saturate. At some particular value of main generator current the differential field just neutralizes the separate excitation, and under those conditions the machine generates only that voltage resulting from the four poles. This is the point C. As the main amperes reduce to zero, the voltage generated by the separately excited windings of the two poles adds to that of the four poles, but due to the saturation of the former, the curve bends over to the point B. Conversely, as the main generator amperes increase above the value at C, the two-pole voltage reverses and subtracts

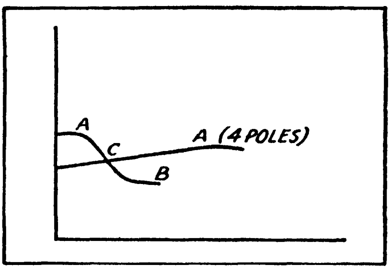


Fig. 21. Modern Westinghouse Differential Exciter Characteristic

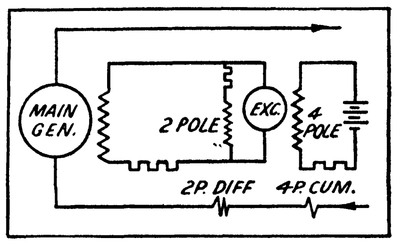


Fig. 22. Simplified Schematic Modern Differential Control

from the four-pole voltage, and again because of the saturation, bends the curve to the point D. The exciter curve thus becomes as shown from B to C to D, which is the desired concave characteristic. As the exciter reproduces its characteristic in the main generator, the main generator characteristic curve becomes that shown by Fig. 20, which gives very satisfactory engine loading. Westinghouse has further studied this problem and, by additional compounding to give the exciter curve as shown in Fig. 21, fills out the points A and B so as to employ full engine horsepower over the widest possible range of speed and tractive effort. In addition, this modern differential control reduces the change in output which had been involved in previous differential control systems due to variation in temperatures of the electrical equipment and consequent changes in resistance of the various field windings. A simple schematic of the modern differential control is shown by Fig. 22.

GENERAL ELECTRIC DRIVE SYSTEM. A schematic diagram of the electric transmission employed by the General Electric

Co. with the Lemp system of automatic control is given in Fig. 22A. It will be noted that the generator has two fields, one a constant shunt field supplied by a separate exciter, the other a differential series field. The effect of the latter is to *reduce* the excitation and therefore the generated voltage when the current output increases. This is just the opposite to the effect of the series field of an ordinary compound-wound generator. The result of the opposed fields is a generator characteristic having the amperage and voltage relations shown in Fig. 22B.

Two traction motor combinations are used. In the first combination the motors are connected in series, and in the second combination in parallel. Referring to Fig. 22A the contactor S is closed

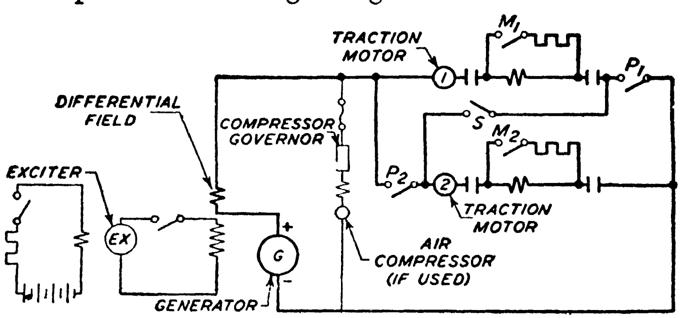


Fig. 22A. Diagram of a General Electric Locomotive Control

for the first motor combination and only contactors P-1 and P-2 are closed for the second combination. In order to develop a high torque, the motors demand a large current from the generator. To make an economical design, the current demand from the generator is reduced to a minimum in the first motor combination by connecting the motors in series, when contactor S is closed. After the locomotive or train is started and speeds up, the torque demand of the motors decreases, which in turn decreases the current demand from the generator. With a decrease in generator current, an increase in generator potential is automatically obtained, as will be seen from Fig. 22B, which results in an increase in the speed of the locomotive.

In the first motor combination, in which the motors are in series across the generator, the voltage across each motor will be one-half that of the generator. At a pre-determined speed, it is the usual

practice to transfer the motors from the first to the second combination in which the motors are connected in parallel. Each motor then has full voltage across the terminals. The locomotive speed is approximately the same just before, during, and after the transfer.

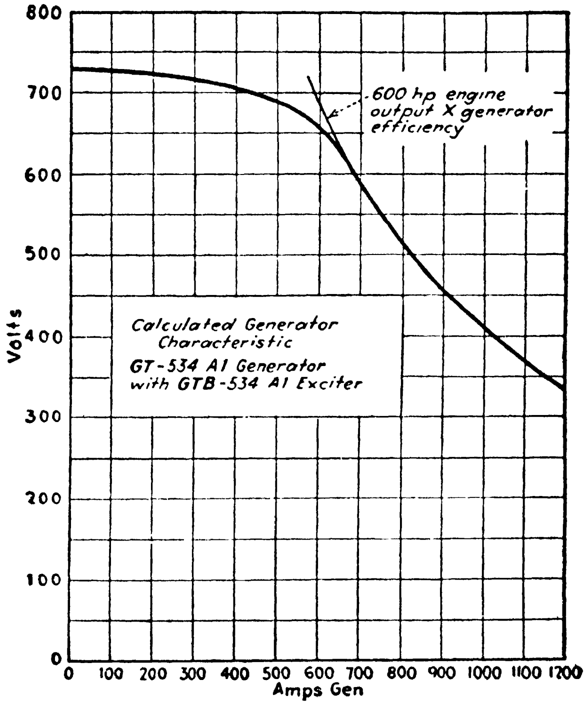


Fig. 22B. Curve Showing Relation of Generator Voltage, and Current
Courtesy of General Electric Company

During this time the torque demand remains the same, so that each motor continues to draw approximately the same current.

Since the motors are connected in parallel after the transfer, the current demand from the generator is then twice as much after as before, or in other words, at least a part of the cycle is repeated over the generator characteristic, but with the motors running at higher speed.

Further increase in motor speed is obtained by shunting (and weakening) the motor fields by means of resistors and switches M1 and M2, Fig. 22A. The current demand for a given motor torque

is greater with reduced field than for full field, resulting in operation over a part of the generator characteristic a third time when the motor fields are shunted.

The electrical equipment is designed to perform the above functions under control of the operator through the engine throttle handle and the controller handle, which are used to start and run the locomotive. The running speed of the locomotive is determined by the speed and output of the engine. The motor combinations are selected by the different operating positions of the controller handle. There are three positions of the controller handle for both the forward and reverse connections, and one "off" position. These operating positions give the first and second motor combinations and, finally, the field shunting of the traction motor.

The engine throttle, which is usually operated manually, controls the fuel input to the engine. After the engines have been started, the operator puts the controller handle in the first operating position, in the desired direction of movement of the train, and then opens the engine throttle. This speeds up the engine and automatically applies power to the traction motors.

As the throttle is opened, the speed of the engine increases and the generator increases its output until at full engine speed the generator is delivering its full load.

After the train has reached a pre-determined speed, the controller handle can be moved from the first to the second operating position, and later from the second to the third, usually with the engine throttle open. Provision is now frequently made in the control so that the operator in starting the locomotive can place the controller handle in the last operating position and the different motor combinations will then be obtained automatically.

ELECTRICAL AUXILIARIES. The electrical auxiliaries of a locomotive usually consist of fan motors for cooling the engine radiators, motor-driven air compressors for furnishing compressed air for the air brakes, motor-driven fans for ventilating the traction motors and some source of power for charging the storage battery. In general, the control of these auxiliaries is a major problem, because they must function properly when operated from a variable-voltage source. With recent improvements in the electrical

equipment, it is now possible to obtain a constant-voltage source with normal variations in engine speed from idling to full speed.

CONTROL APPARATUS AND CIRCUITS. Any Diesel electric control system must of necessity include a variety of items. There are, in general, eleven types of control items used for full and complete control, protection, and utilization of the engine power and for control of train movement. These are as follows:

Contactors—(where limited currents are handled, Fig. 23).

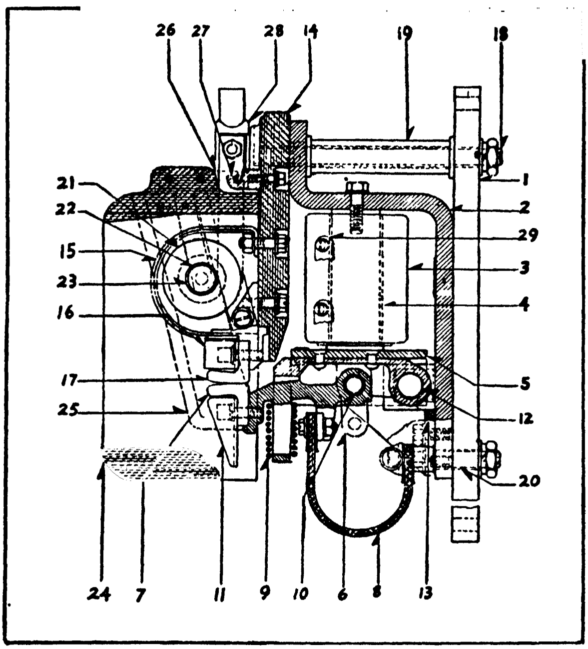


Fig. 23. Railway Contactor

Ref. No.	Description of Part
1	Base
2	Frame
3	Operating coil
4	Core for operating coil
5	Armature lever and plate
6	Moving contact support
7	Moving contact tip
8	Shunt with clips
9	Spring
10	Hinge pin for moving contact
11	Arcing horn
12	Hinge pin for armature
13	Bearing bracket
14	Base for stationary contact
15	Support with arc horn
16	Arcing horn for stationary contact
17	Stationary contact tip
18	Insulated stud for frame and contact support base
19	Spacer, for stud
20	Insulated stud to fasten shunt to base
21	Blowout coil
22	Core for blowout coil
23	Insulation tube for core
24	Arc box
25	Pole piece
26	Hinge side plate
27	Hinge for arc box
28	Copper tube terminal
29	Terminal clip

Electro-pneumatically Operated Unit Switches—(where large currents are to be interrupted, Fig. 24)

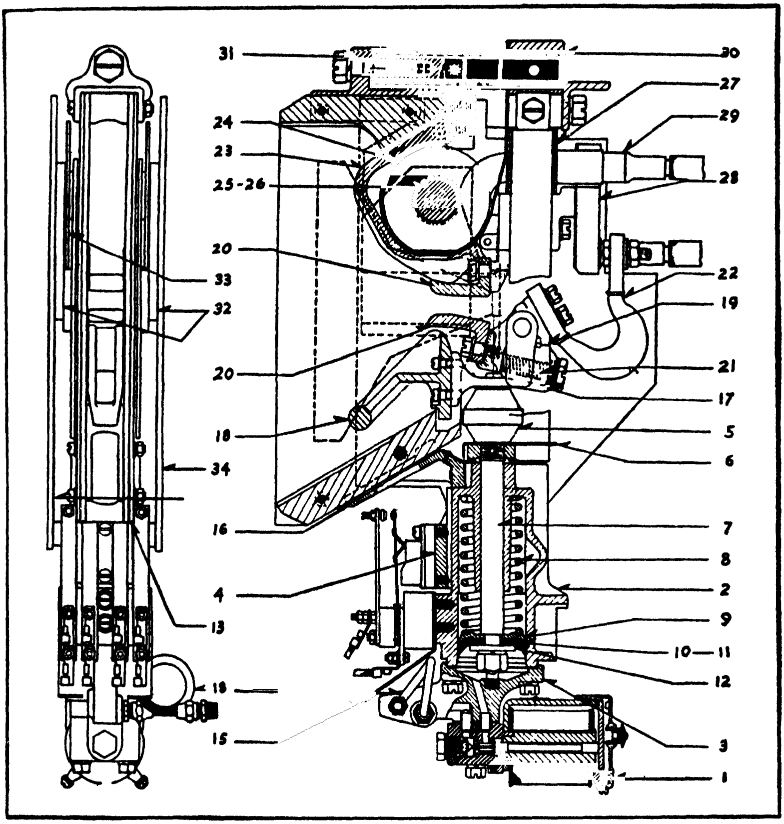


Fig 24. Unit Switch

Ref No	Description of Part	Ref No	Description of Part
1	Magnet valve	18	Lower arc horn
2	Air cylinder	19	Contact support
3	Cylinder cap	20	Contact
4	Interlock bracket	21	Spring
5	Piston insulator	22	Shunt
6	Insulation shield	23	Upper arc horn with blowout coil
7	Piston rod	24	Insulation for blowout coil
8	Piston spring	25	Core for blowout coil
9	Follower washer	26	Insulation for core
10	Piston packing	27	Insulation spacer
11	Piston packing expander	28	Terminal base
12	Piston washer	29	Terminal
13	Side bar, R H	30	Insulation tube with plugs
14	Air connection	31	Arc box bracket
15	Insulation for interlock	32	Pole pieces
16	Arc box guide	33	Pole piece insulation
17	Contact support yoke	34	Barriers

Traction Motor Reversers–(Fig. 25)

Controllers

Engine Governor Operators

Push Button Boxes for Auxiliary Circuits–(Fig. 26)

Relays: Regulating, Reverse Current, Transition, Ground Protection, Etc.

Knife Switches

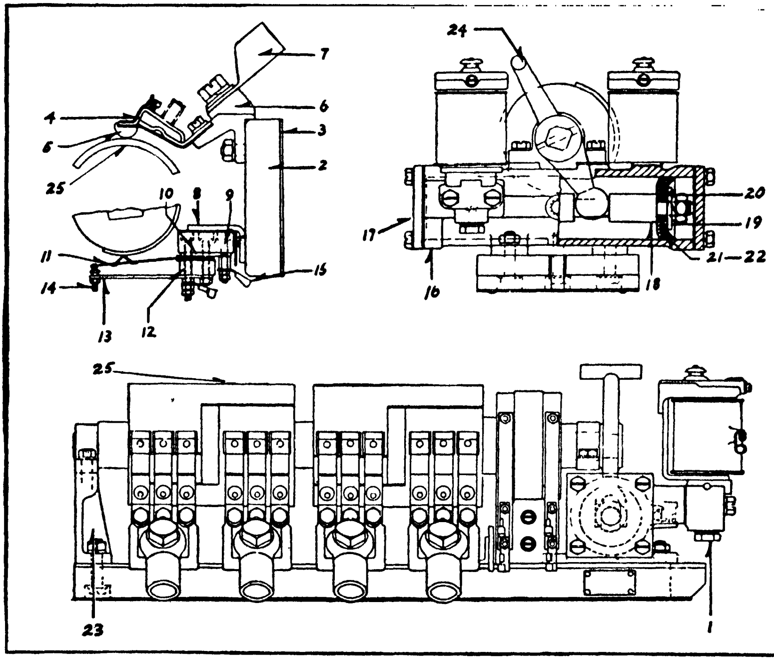


Fig. 25. Railway Reverser

Ref. No.	Description of Part
1	Magnet valve
2	Finger board
3	Insulation for board
4	Main finger
5	Finger tip
6	Finger base
7	Terminal
8	Support
9	Finger block
10	Finger base
11	Finger
12	Spacer
13	Contact support

Ref No.	Description of Part
14	Contact
15	Terminal clip
16	Air cylinder
17	Cylinder cap
18	Piston rod
19	Piston washer
20	Follower washer
21	Expander
22	Piston packing
23	Bearing bracket
24	Cylinder lever
25	Drum contacts

Resistors

Fuses

Meters

While these items may vary in size and arrangement, depending upon their purpose (such as contactors, different sizes being used for traction motor field shunting and for generator field circuits), all must be especially designed for railway service. It has been found by experience that equivalent apparatus which will operate successfully in industrial service cannot be operated without trouble on a railway vehicle.

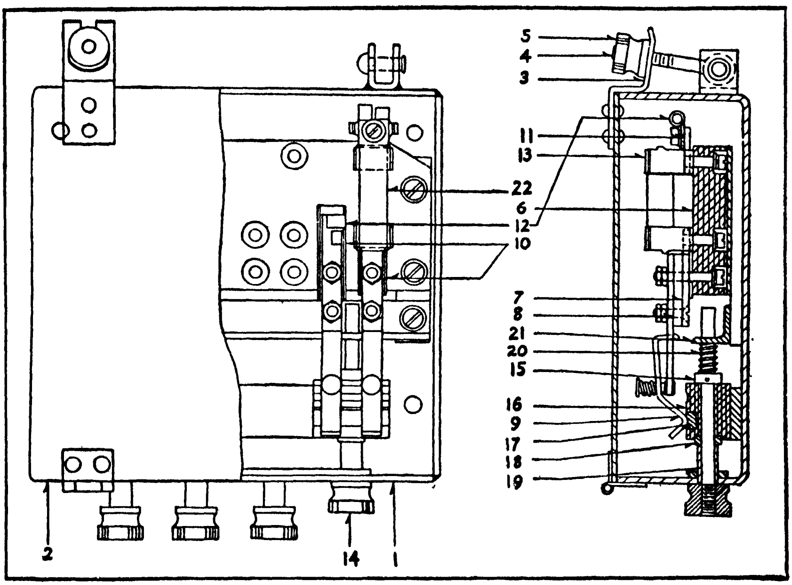


Fig. 26. Push Button Box

Ref. No.	Description of Part	Ref. No.	Description of Part
1	Box	13	Fuse clip
2	Cover with latch	14	Push rod
3	Latch	15	Collar
4	Eye bolt	16	Contact block
5	Thumb nut	17	Contact
6	Finger board	18	Collar
7	Finger base	19	Sleeve
8	Spacer	20	Spring, used on engine start button, etc.
9	Finger	21	Guide
10	Finger shields	22	Fuse
11	Terminal block		
12	Terminal clip		

KEYS TO THE STUDY OF DIESEL ELECTRIC SYSTEMS. A Diesel electric equipment may consist of any desired combination of generators and traction motors, also, while the electrical circuits are basically the same, there are many ways in which these combinations may be connected. For the sake of simplicity, Fig. 27 shows a single generator (GEN) providing electrical power for two traction motors (No. 1 and No. 2), the latter being connected in parallel (with each other). Current flowing from the positive side of the generator (+) by way of conductor G+, divides and passes through two switches, P1 and P2 (when these are closed), to the traction motor armatures No. 1 and No. 2. After passing through these armatures the current flows to the respective reverser con-

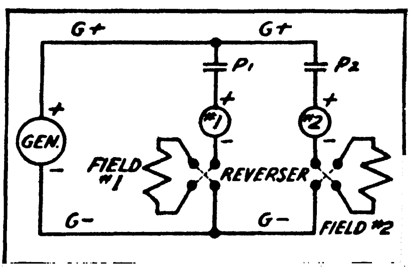


Fig. 27. Basic Power Circuits for Diesel Electric Motive Power. Parallel Motors

tacts, thence passing through the motor field windings and back to the reverser contacts, from which point it returns to the negative side of the generator (—) via conductor G—. Reverser contacts are arranged so that the current may be passed through the fields in one direction or the other to secure the direction of motor rotation desired. From this it may be seen that with the generator producing voltage and the switches P1 and P2 closed, the motors will tend to rotate and move the train. If the generator voltage is low the train may move slowly, while if the voltage is high it may travel fast, that is, the speed of each motor when developing a given tractive force will vary somewhat as the voltage varies.

It may be noted from Fig. 27 that the current which flows from the generator must be twice as great as that which flows through each motor. When starting a train, the heavy current re-

quired for each motor imposes double this current value on the generator, which is sometimes considered to be excessively severe for the generator. To reduce the generator current value during starting, then, the traction motors may first be connected in series and then later be connected in their normal parallel relation. These connections are shown by Fig. 28. In this instance, current first passes from the generator, through G+ conductor, through motor No. 1, through switch S (which is the first one to be closed), then through motor No. 2 and back to the generator via conductor G. In this manner full starting current equivalent to that of but one motor is all that is drawn from the generator. In this case, however, the maximum voltage which each motor gets is but half of that generated, so the minimum train speed with these connections

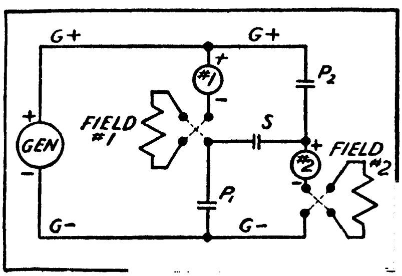


Fig. 28. Deviation from Basic Circuits for Diesel Electric Motive Power. Series, Parallel Motor Connections

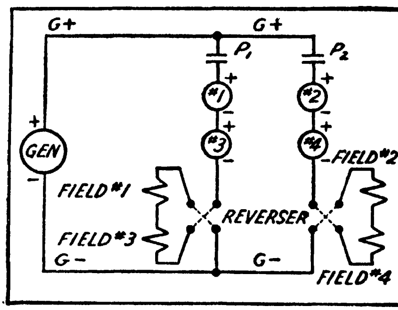


Fig. 29. Basic Power Circuits for One Generator and Four Traction Motors. Series, Parallel Connections

is, roughly, half of the full train speed. As the train speeds up to half speed, however, the current drawn by the traction motors decreases to a value which will not overload the generator if the motors are connected in parallel. The second step of a train acceleration, then, is to close switch P1, open switch S, and then close switch P2, which places both motors in parallel across the generator.

In most of the larger sizes of Diesel switching locomotives it is customary to use one engine and generator and four traction motors. Because it is easier to build a generator having double normal voltage than to build one having excessive current capacity, such switchers usually have two motors grouped permanently in series and two such groups connected in parallel or in the series, parallel relations similar to Fig. 28. Fig. 29 shows a 4-motor grouping.

Diagrams are usually available for Diesel electric motive power. After a study of Figs. 27, 28 and 29, it should be relatively simple to trace out the scheme of connections for any particular unit. It may be pointed out that the designing engineer who lays out a Diesel electric transmission system first prepares a *schematic diagram* showing the scheme of electrical connections by a relatively simple line diagram embodying as few turns and crosses of the lines as

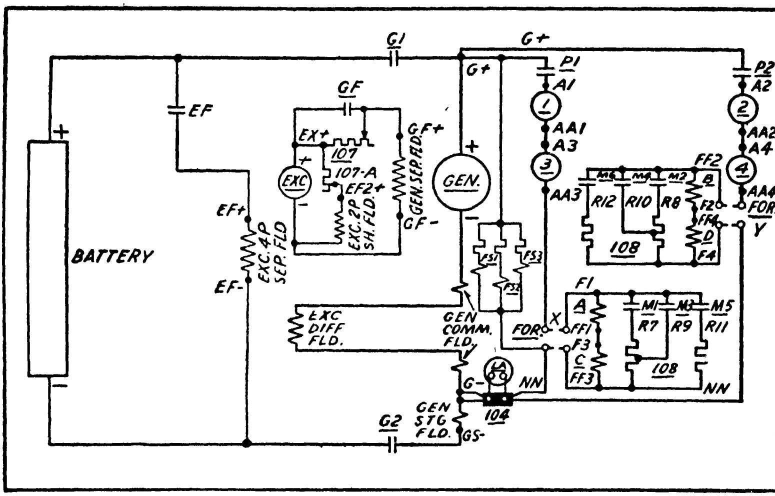


Fig. 30. Schematic Diagram of Main Circuits

possible, from which he later prepares the actual *wiring diagram* to correspond more nearly to actual locations and conduit runs of the motive power unit itself. Much more information as to the actual functioning of the equipment may be obtained from the schematic diagram than from the wiring diagram.

Referring to Fig. 30, this diagram represents the main power circuits of a 1000 horsepower Diesel locomotive. Before following this through, it is necessary to identify each piece of apparatus. The various exciter and generator field coils are labeled and are readily distinguished. The other items are as follows:

EF, G_1, G_2, *GF*, M_1 *to* M_6 = Magnetic contactors.

P_1, P_2 = Pneumatically closed contactors.

GEN. = Main generator. *EXC.* = Exciter.

1, 2, 3, 4 = *Traction motor armatures.*
A, B, C, D = Traction motor fields. *107, 108* = Resistors.
LA = Load ammeter. *104* = Ammeter shunt.
X, Y = Reverser contacts. FS_1 to FS_3 = Voltage relay coils.

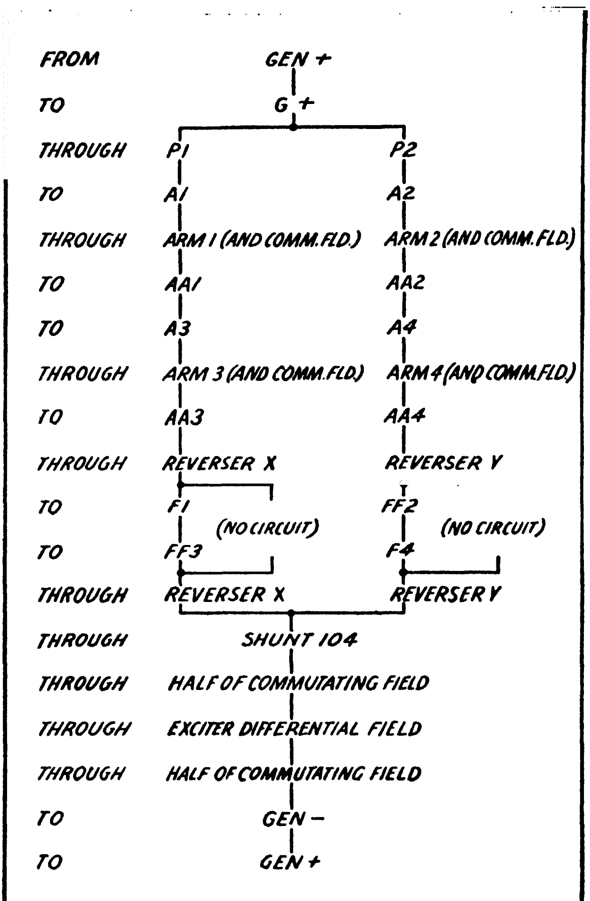


Fig. 31. Tracing Through Main Circuits

In tracing through the electrical connections of a diagram, it always simplifies the process if the initial starting point is taken as the positive (+) side of a source of electrical energy, such as a generator, a storage battery or a trolley wire (if any power is received from an outside source).

Figs. 31 to 34 show a method of following through the main power circuits of Fig. 30. Fig. 31 shows the first step in the application of propulsion power. As the train accelerates, it is desirable to

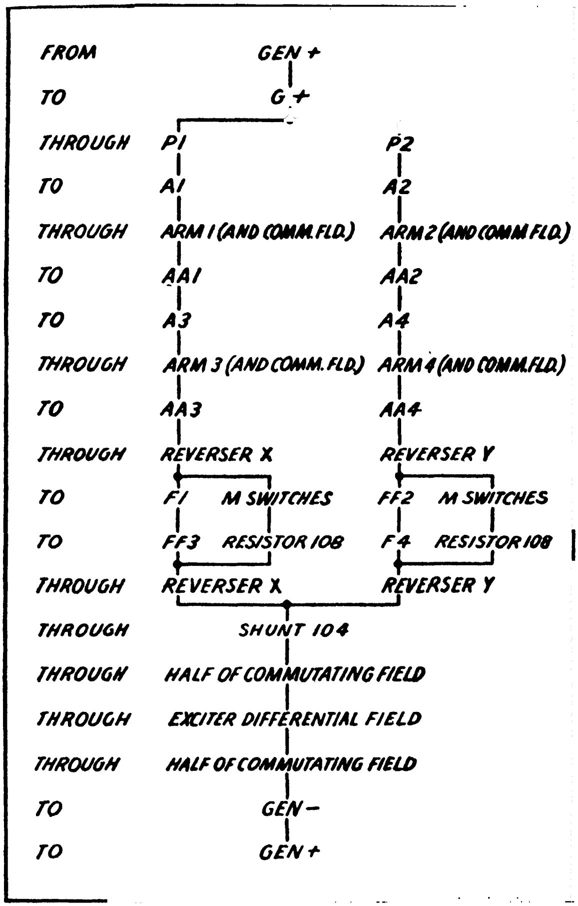


Fig. 32. Tracing Through Main Circuits

shunt the traction motor fields to increase the speed, in which case the circuit reads as shown by Fig. 32.

Fig. 33 traces the excitation circuits of the main generator, as shown by Fig. 30. One other function is shown in Fig. 30—that of starting the Diesel engine by using the main generator as a motor,

the circuits being shown by Fig. 34. In this case, the exciter differential field has no effect, since the exciter circuits are not functioning. The starting field acts in the same way as the field of a series traction motor and causes the generator to rotate and thereby spin the engine for starting purposes.

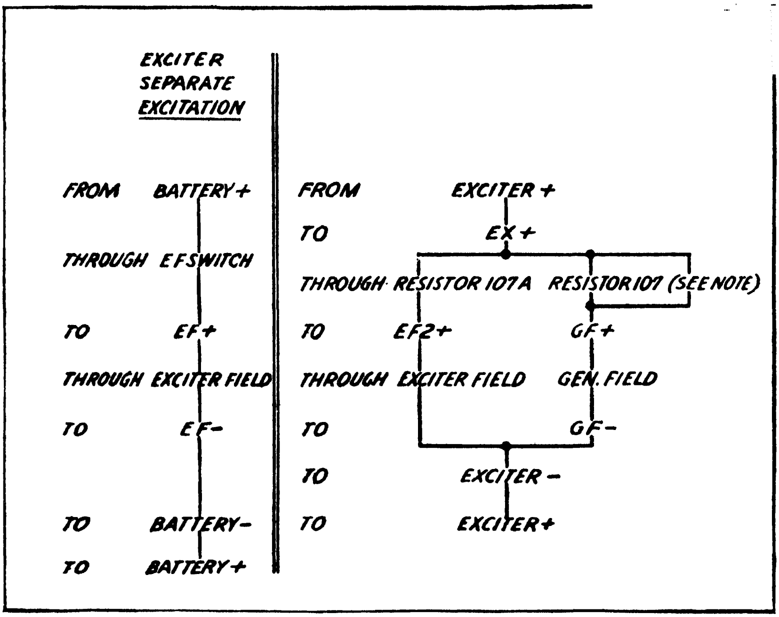


Fig. 33. Tracing Through Exciter Circuits

Note: When engine idles, "GF" switch is open. When engine develops propulsion power, GF switch closes and short circuits resistor *107.*

The control circuits are somewhat more difficult to follow through because there are so many more of them. The prime purpose of control circuits, of course, is merely to cause the contactors in the main power circuits, Fig. 30, to close or open at the proper time, to move the reverser to the position which gives the desired direction of train movement, to control the engine speed, and to insure that the circuits cannot be improperly set up. Referring to the control circuit schematic, Fig. 35, the first step is to identify each piece of apparatus shown and to determine how it functions.

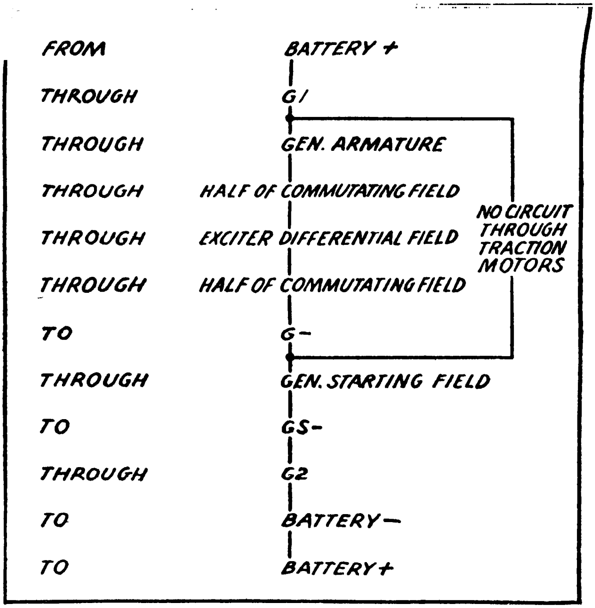


Fig. 34. Tracing Through Starting Circuits

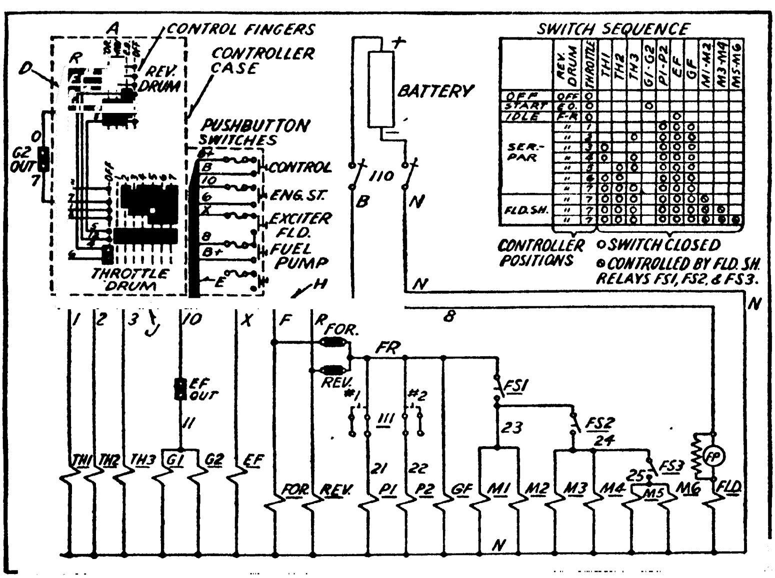


Fig. 35. Control Schematic Diagrams

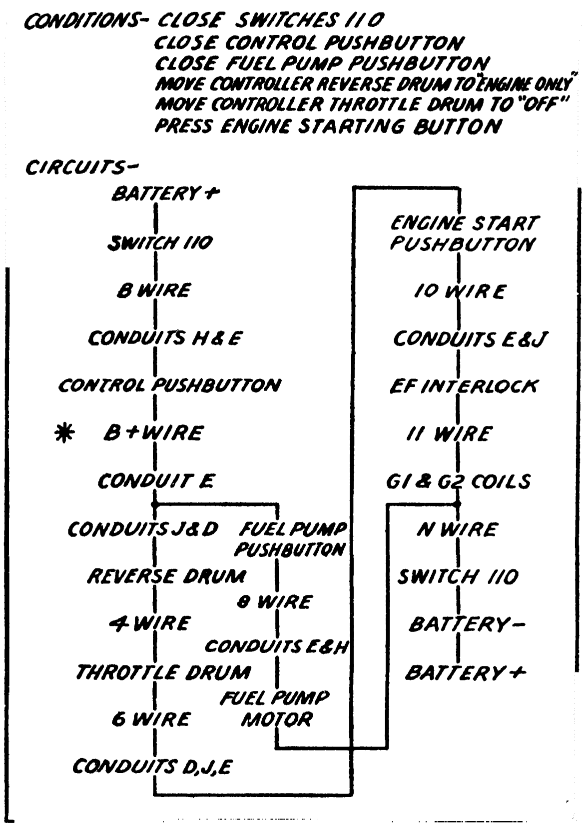


Fig. 36. Tracing Through Starting Control

Thus:

A .... Cylindrical drums carrying contact plates. Turning the drums moves the contact plates under the control fingers to make electrical contact.

EO .... "Engine Only" position of the reverse drum.

Shaded areas ... The contact plates of the drums.

Heavy Black lines ..... Conduit carrying many wires.

G2 OUT....... Interlock–makes circuit when G2 contactor (see Fig. 30) is open (out).

EF OUT ...... Interlock.

FOR (REV) ... Interlocks making circuit when the reverser is in the forward (or reverse) positions.

*Control operations of Figs. 37 and 38 obtain power from here. (See Fig. 36.)

110	Knife switches for isolating the battery.
111	Knife switches for cutting out traction motors (prevent them from operating).
FS1, FS2, FS3..	Contacts made by relays. FS1 closes at 600 volts across the generator, FS2 at 625 volts, and FS3 at 650 volts.
Coils TH1, TH2, TH3	The three coils moving the throttle operator. Various combinations give different lengths of throttle operator movement.
G1, G2, EF, P1, P2, GF, M1, M2, M3, M4, M5, M6	Operating coils of their respective contactors (See Fig. 30).
FP	Fuel pump motor.
FOR REV Coils	Coils to move the reverser to its corresponding position.

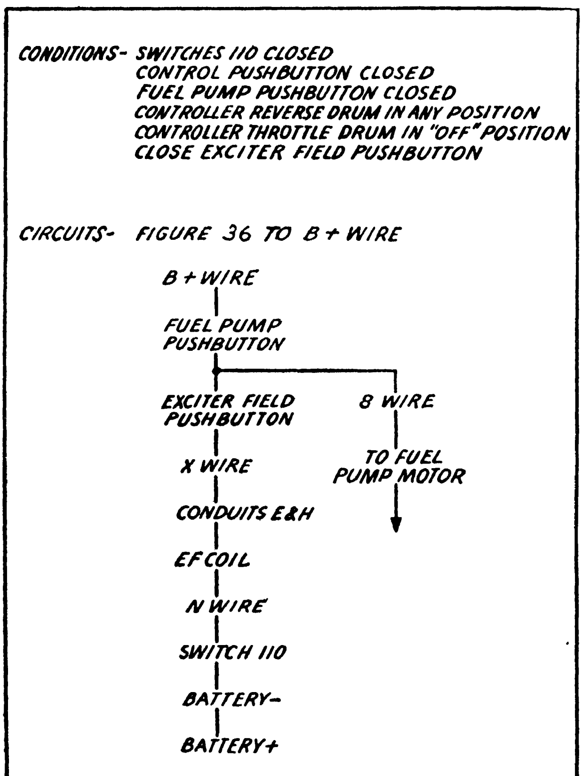


Fig. 37. Tracing Through Idling Circuits

Note that the ENG ST (Engine Starting) push button has a spring under it to return it to the open position when the pressure is released. In upper right-hand corner of diagram, Fig. 35, is a

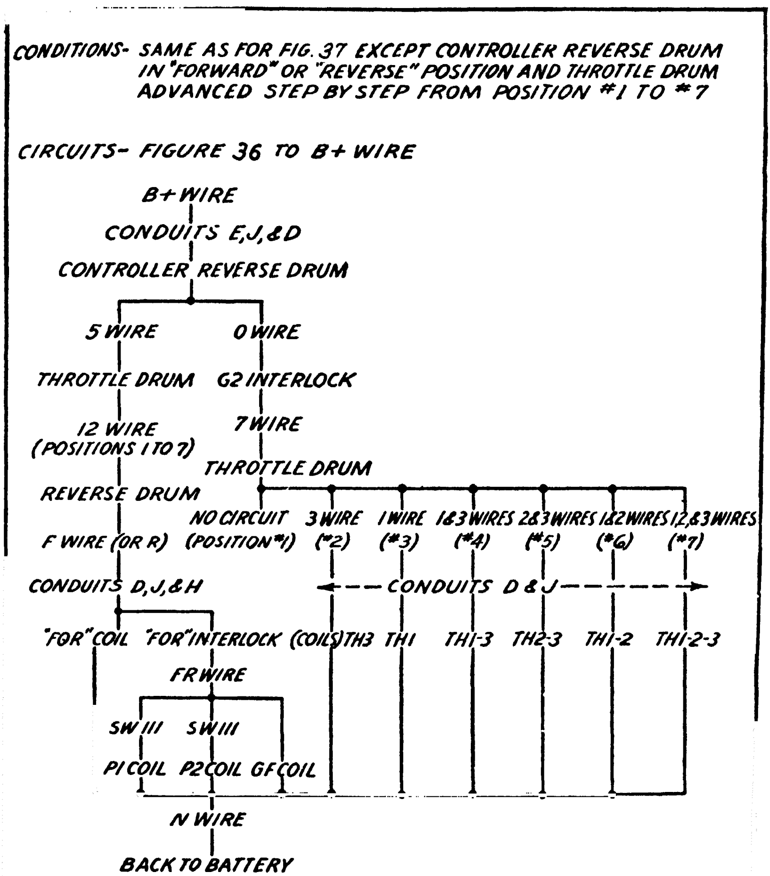


Fig. 38. Tracing Through Power-On Circuits

table which shows which devices are operated for each condition of operation.

Fig. 36 follows the engine starting procedure through. Fig. 37 outlines the circuits for normal idle position. Throttle drum positions No. 1 to No. 7 are all the same except that different coils of the throttle operator are energized to give the progressive advance-

ment of the engine throttle (setting of the engine governor). The circuits for each position of the controller throttle drum are shown by Fig. 38.

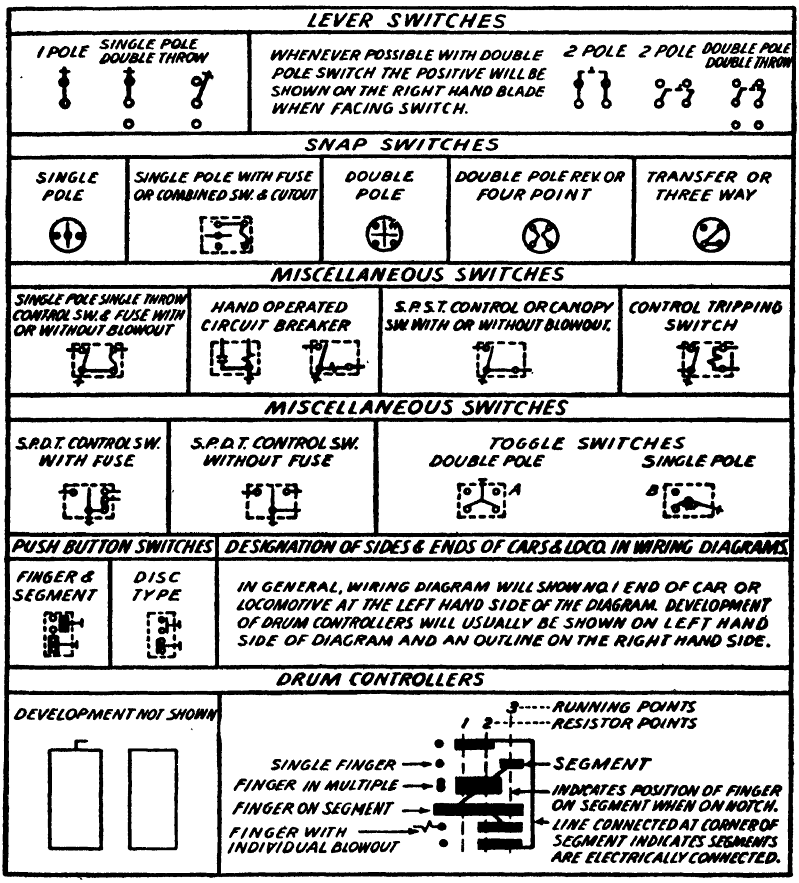
When the voltage of the main generator reaches 600 volts, the FS1 relay closes (Fig. 30 shows three coils connected to be energized by the voltage of the main generator) and establishes a circuit from the FR wire (Fig. 35) to 23 wire, thereby energizing coils M1 and M2. Likewise, FS2 relay and FS3 relay bring in additional traction motor field shunting switches, M3, M4, M5, and M6 in two progressive steps as the generator voltage rises.

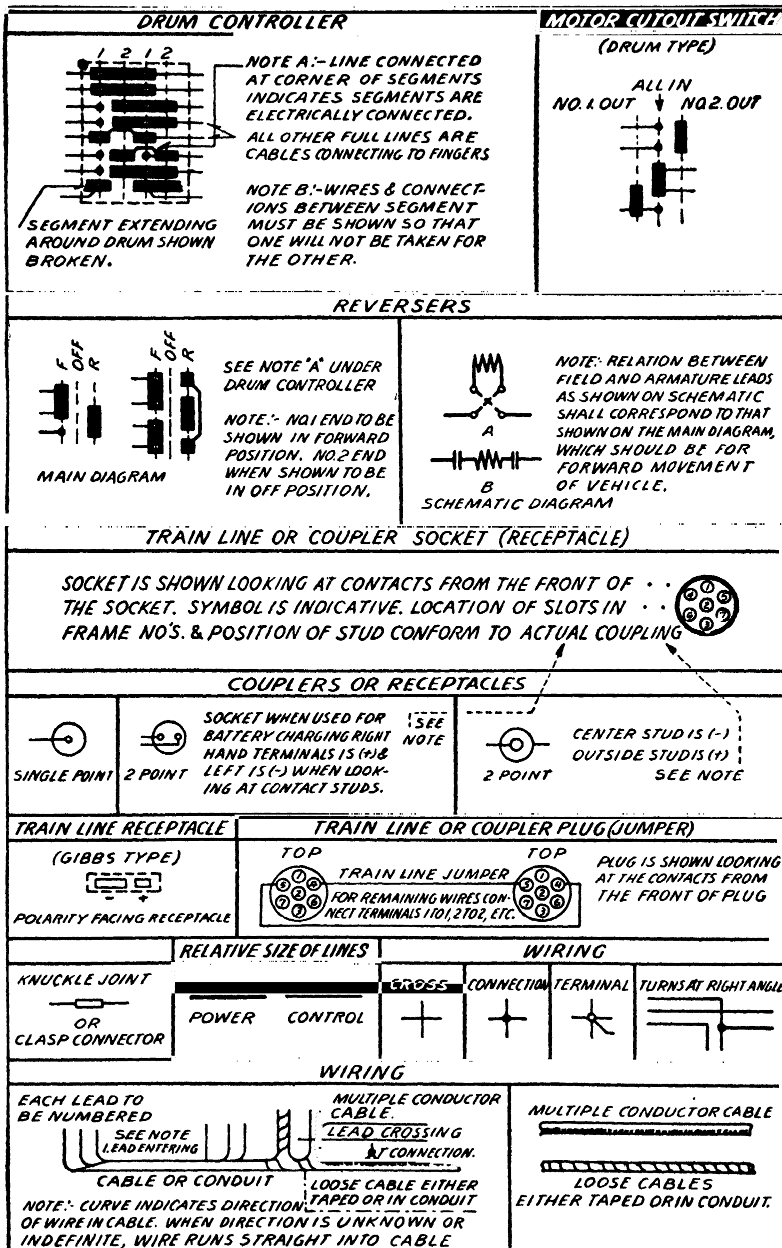
Figs. 30 to 38 illustrate the method of tracing out the circuits for the purpose of determining which of the relays, coils, and apparatus are energized or operated under the different control conditions. It is always necessary to consult the main circuit schematic diagram (such as Fig. 30) in following through the control circuit schematic (such as Fig. 35) in order to see what happens to the power delivery each time the coil of a switch is energized or a relay is operated.

There are, of course, many types of diagrams. This discussion has covered one of the simplest systems of electrical control in use for the larger sizes of switching locomotives. The fundamental idea, however, is the same for all diagrams, and with the exercise of patience, any circuit may be understood by knowing the symbols used and also the purpose and functioning of each piece of apparatus.

SYMBOLS

To permit of ready interpretation of diagrams as used with Diesel Electric motive power, drawings of the diagram symbols commonly used are included here. There are, from time to time, slight deviations from these, but familiarity with the normal usage will clarify practically any diagram.

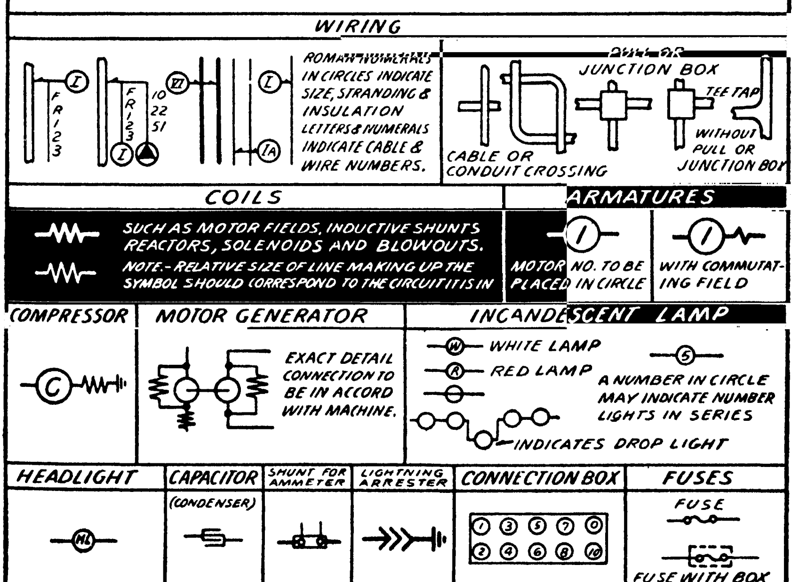


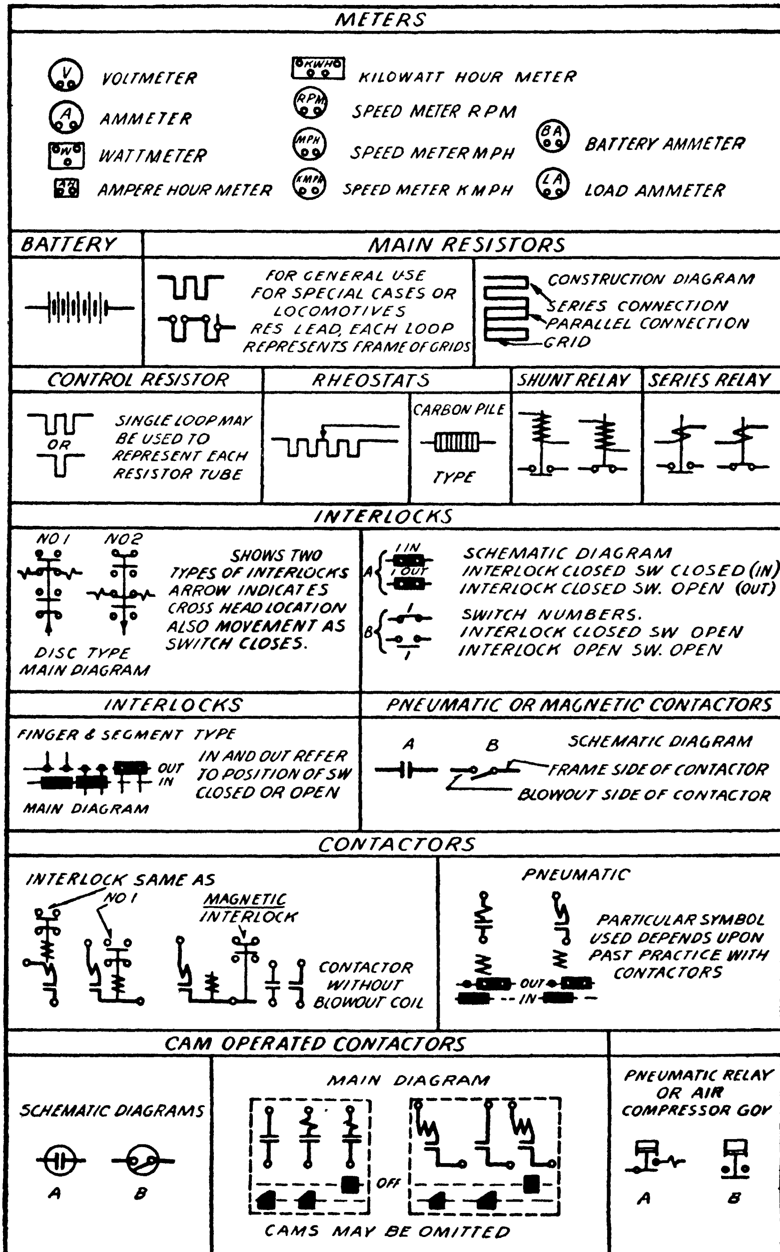

DRUM CONTROLLER
1 2 1 2
NOTE A:- LINE CONNECTED AT CORNER OF SEGMENTS INDICATES SEGMENTS ARE ELECTRICALLY CONNECTED.
ALL OTHER FULL LINES ARE CABLES CONNECTING TO FINGERS
NOTE B:- WIRES & CONNECTIONS BETWEEN SEGMENT MUST BE SHOWN SO THAT ONE WILL NOT BE TAKEN FOR THE OTHER.
SEGMENT EXTENDING AROUND DRUM SHOWN BROKEN.
MOTOR CUTOUT SWITCH
(DRUM TYPE)
ALL IN
NO. 1 OUT
NO. 2 OUT
REVERSERS
F OFF R
SEE NOTE 'A' UNDER DRUM CONTROLLER
NOTE:- NO. 1 END TO BE SHOWN IN FORWARD POSITION. NO. 2 END WHEN SHOWN TO BE IN OFF POSITION.
MAIN DIAGRAM
A
B
SCHEMATIC DIAGRAM
NOTE:- RELATION BETWEEN FIELD AND ARMATURE LEADS AS SHOWN ON SCHEMATIC SHALL CORRESPOND TO THAT SHOWN ON THE MAIN DIAGRAM, WHICH SHOULD BE FOR FORWARD MOVEMENT OF VEHICLE.
TRAIN LINE OR COUPLER SOCKET (RECEPTACLE)
SOCKET IS SHOWN LOOKING AT CONTACTS FROM THE FRONT OF THE SOCKET. SYMBOL IS INDICATIVE. LOCATION OF SLOTS IN FRAME NO'S. & POSITION OF STUD CONFORM TO ACTUAL COUPLING
COUPLERS OR RECEPTACLES
SINGLE POINT
2 POINT
SOCKET WHEN USED FOR BATTERY CHARGING RIGHT HAND TERMINALS IS (+) & LEFT IS (-) WHEN LOOKING AT CONTACT STUDS.
SEE NOTE
2 POINT
CENTER STUD IS (-)
OUTSIDE STUD IS (+)
SEE NOTE
TRAIN LINE RECEPTACLE
(GIBBS TYPE)
POLARITY FACING RECEPTACLE
TRAIN LINE OR COUPLER PLUG (JUMPER)
TOP
TOP
TRAIN LINE JUMPER
FOR REMAINING WIRES CONNECT TERMINALS 1 TO 1, 2 TO 2, ETC.
PLUG IS SHOWN LOOKING AT THE CONTACTS FROM THE FRONT OF PLUG
KNUCKLE JOINT
OR
CLASP CONNECTOR
RELATIVE SIZE OF LINES
POWER
CONTROL
WIRING
CROSS
CONNECTION
TERMINAL
TURNS AT RIGHT ANGLE
WIRING
EACH LEAD TO BE NUMBERED
SEE NOTE LEAD ENTERING
CABLE OR CONDUIT
MULTIPLE CONDUCTOR CABLE.
LEAD CROSSING
AT CONNECTION.
LOOSE CABLE EITHER TAPED OR IN CONDUIT
NOTE:- CURVE INDICATES DIRECTION OF WIRE IN CABLE. WHEN DIRECTION IS UNKNOWN OR INDEFINITE, WIRE RUNS STRAIGHT INTO CABLE
MULTIPLE CONDUCTOR CABLE
LOOSE CABLES EITHER TAPED OR IN CONDUIT.

GROUND	WIRING SYMBOLS INDICATING CABLE SIZES ON WIRING DIAGRAMS
	(I) WITH SUB LETTER AS (IA) (IB) FOR CONTROL EITHER SINGLE WIRES OR TRAIN LINES.
	(II) WITH SUB LETTERS AS (IIA) (IIB) FOR AUXILIARY CIRCUITS SUCH AS LIGHTING, COMPRESSOR, ETC.
	(III) MOTOR CIRCUIT BUS LINE.
	(IV) FOR THIRD RAIL SHOE.
	(V) WITH SUB LETTERS (VA) (VB) FOR TROLLEY LEADS
	(VI) WITH SUB LETTERS (VIA) (VIB) FOR MOTOR LEADS.
	(IX) WITH SUB LETTERS (IXA) (IXB) FOR BUS BARS.
	(X) RESISTOR WITH SUB LETTERS (XA) (XB) ETC.
	(▲) CABLE OR CONNECTION SHOWN BUT NOT FURNISHED AS PART OF EQUIPMENT.

WIRING SYMBOLS IDENTIFYING DEVICES ON CAR WIRING DIAGRAMS

R, R1, RR, RR1 =	RESISTOR CONTACTORS	OV =	OVERVOLTAGE RELAY
S =	SERIES CONTACTORS	VR =	VOLTAGE REGULATOR
P =	PARALLEL CONTACTORS	G =	GROUND, ALSO STARTING CONTACTORS
F, FOR. =	FORWARD POSITION OF REVERSER	GP =	PARALLEL TIE CONTACTOR
R, REV =	REVERSE POSITION OF REVERSER	RC =	REVERSE CURRENT
N =	COMMON RETURN	AF =	AUXILIARY FIELD CONTACTOR
M =	FIELD CONTACTORS	GF =	GENERATOR FIELD CONTACTOR
G =	MAIN GENERATOR	TR =	TRANSITION RELAY
AG =	AUXILIARY GENERATOR	TH =	THROTTLE DEVICE COIL
CG =	CONTROL GENERATOR	A =	AUXILIARY CIRCUIT CONTACTOR
E =	EXCITER	LA =	LOAD AMMETER
C =	COMPRESSOR	BA =	BATTERY AMMETER
W =	RADIATOR FAN MOTOR	FS =	FIELD SHUNT RELAY
BI =	TRACTION MOTOR BLOWER MOTOR		




METERS
VOLTMETER
AMMETER
WATTMETER
AMPERE HOUR METER
KILOWATT HOUR METER
SPEED METER RPM
SPEED METER MPH
SPEED METER KMPH
BATTERY AMMETER
LOAD AMMETER
BATTERY
MAIN RESISTORS
FOR GENERAL USE
FOR SPECIAL CASES OR LOCOMOTIVES
RES LEAD, EACH LOOP REPRESENTS FRAME OF GRIDS
CONSTRUCTION DIAGRAM
SERIES CONNECTION
PARALLEL CONNECTION
GRID
CONTROL RESISTOR
OR
SINGLE LOOP MAY BE USED TO REPRESENT EACH RESISTOR TUBE
RHEOSTATS
CARBON PILE
TYPE
SHUNT RELAY
SERIES RELAY
INTERLOCKS
NO 1
NO 2
SHOWS TWO TYPES OF INTERLOCKS ARROW INDICATES CROSS HEAD LOCATION ALSO MOVEMENT AS SWITCH CLOSES.
DISC TYPE
MAIN DIAGRAM
A
I IN
I OUT
B
SCHEMATIC DIAGRAM
INTERLOCK CLOSED SW CLOSED (IN)
INTERLOCK CLOSED SW. OPEN (OUT)
SWITCH NUMBERS.
INTERLOCK CLOSED SW OPEN
INTERLOCK OPEN SW. OPEN
INTERLOCKS
FINGER & SEGMENT TYPE
OUT
IN
IN AND OUT REFER TO POSITION OF SW CLOSED OR OPEN
MAIN DIAGRAM
PNEUMATIC OR MAGNETIC CONTACTORS
A
B
SCHEMATIC DIAGRAM
FRAME SIDE OF CONTACTOR
BLOWOUT SIDE OF CONTACTOR
CONTACTORS
INTERLOCK SAME AS NO 1
MAGNETIC INTERLOCK
CONTACTOR WITHOUT BLOWOUT COIL
PNEUMATIC
PARTICULAR SYMBOL USED DEPENDS UPON PAST PRACTICE WITH CONTACTORS
OUT
IN
CAM OPERATED CONTACTORS
SCHEMATIC DIAGRAMS
A
B
MAIN DIAGRAM
OFF
CAMS MAY BE OMITTED
PNEUMATIC RELAY OR AIR COMPRESSOR GOV
A
B

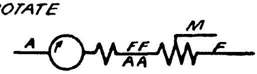
LEAD	MARKING
ARMATURE (CONNECTED TO BRUSH HOLDER)	A
ARMATURE (CONNECTED TO BRUSH HOLDER OR TO COMMUTATING FIELD)	AA
MAIN FIELD	F AND FF
FIRST FIELD CONTROL LEAD	M
SECOND FIELD CONTROL LEAD	MM
WHEN THE COMMUTATING FIELD WINDINGS ARE NOT PERMANENTLY CONNECTED TO THE ARMATURE, THE EXTERNAL LEADS WILL BE MARKED.- COMMUTATING FIELD	C AND CC

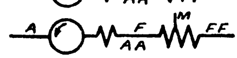
WITH CURRENT PASSING THROUGH THE MOTORS AS INDICATED BY ARROWS THE ARMATURE ROTATION WILL BE

CLOCKWISE WITH MARKING 

COUNTER-CLOCKWISE WITH MARKING 

FIELD CONTROL MOTOR ARMATURE WILL ROTATE

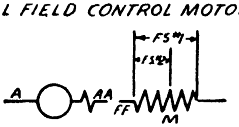
CLOCKWISE WITH MARKING 

COUNTER CLOCKWISE WITH MARKING 

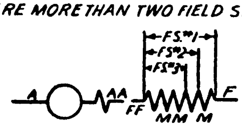
NOTE # DIRECTION OF ROTATION IS SHOWN BY ARROW. MOTOR IS VIEWED FROM COMMUTATOR END.

THE SECTION OF FIELD WINDING IN CIRCUIT TO GIVE VARIOUS FIELD STRENGTHS ARE'—

USUAL FIELD CONTROL MOTORS



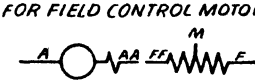
WHERE MORE THAN TWO FIELD STRENGTH



MAIN WIRING DIAGRAM WILL SHOW MARKINGS AS FOLLOWS:-

FOR NON-FIELD CONTROL MOTORS.

FOR FIELD CONTROL MOTORS



WHERE SEPARATE COMMUTATING FIELD WINDINGS ARE USED

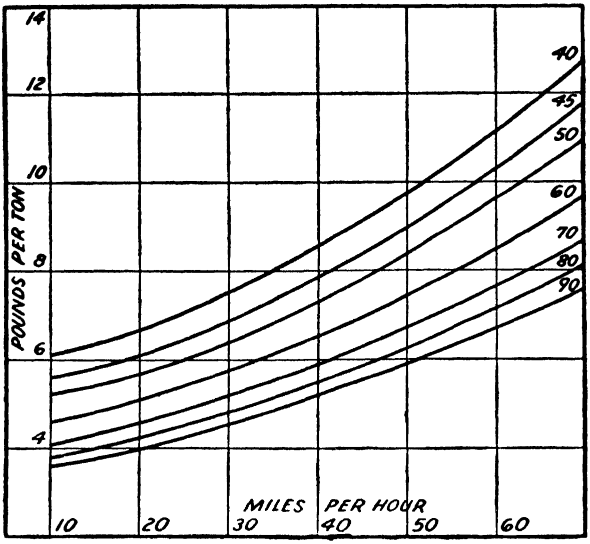


Fig. 41. 6-Axle Passenger Car Resistance

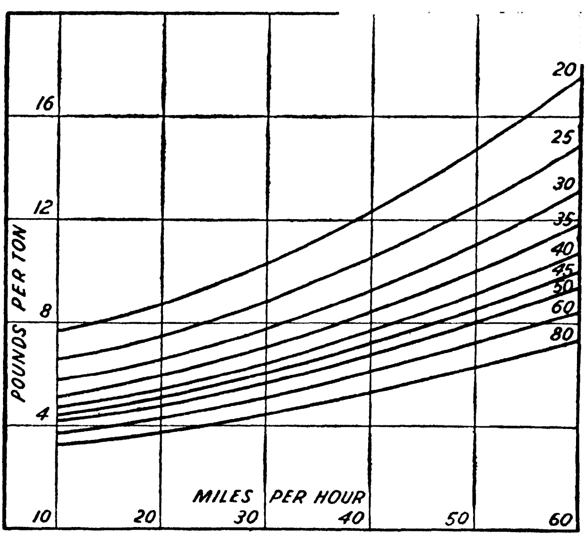


Fig. 42. 4-Axle Freight Car Resistance

GRADE RESISTANCE. The per cent grade is the number of feet rise per 100 feet length of track. Use 20 pounds resistance per ton of train weight for each per cent of grade. Thus:

Per Cent Grade	Resistance Per Ton	Per Cent Grade	Resistance Per Ton	Per Cent Grade	Resistance Per Ton
0.25......	5 lbs.	1.25......	25 lbs.	2.25......	45 lbs.
0.50......	10 lbs.	1.50......	30 lbs.	2.50......	50 lbs.
0.75......	15 lbs.	1.75......	35 lbs.	2.75......	55 lbs.
1.00......	20 lbs.	2.00......	40 lbs.	3.00......	60 lbs.

This results from the fact that on a 1 per cent grade a ton (2,000 lbs.) must be raised one foot for each hundred feet that the train advances: $\frac{2{,}000 \text{ lbs.} \times 1 \text{ ft.}}{100 \text{ ft.}} = 20$ pounds

CURVE RESISTANCE. A one degree curve is one in which a hundred feet of track is $\frac{1}{360}$ of a complete circle. Curve resistance is estimated by various engineers from .4 to .8 pound per ton of train weight for each degree of curvature. In determining such resistance for performance calculations, however, it is safer to use .8 pound to 1 pound per ton of weight of that portion of the train which is in the curve.

ACCELERATION. The force required to accelerate a ton of train weight at a rate of one mile per hour each second, or 1.466 feet per second per second (fpsps), is (for acceleration in a straight line): Force = 91.1 pounds

There is another element which enters into this, however. This is the rotational acceleration of wheels, axles, motors, gears, etc., variously estimated to require 5 to 12 per cent more accelerating force. It has been found convenient to estimate that this requires 9.8 per cent greater force than for straight horizontal train acceleration, so that:

One mile per hour per second acceleration requires a net force of 100 pounds per ton of train weight.

Thus, if the net tractive force available for accelerating a 1,000-ton train were 25,000 pounds (after accounting for all resistances), the acceleration would be $\frac{25{,}000 \text{ lbs.}}{1{,}000 \text{ tons}} = 25$ pounds per ton or an acceleration of .25 miles per hour per second.

BALANCING SPEED. The train speed at which all of the available tractive force is used to overcome the various resistances to train movement (leaving no net tractive force for acceleration) is called the *balancing* or *free-running speed.*

SPEED

1 m.p.h. =	1.466	ft. per second
10 m.p.h. =	14.66	ft. per second
20 m.p.h. =	29.33	ft. per second
30 m.p.h. =	44.00	ft. per second
40 m.p.h. =	58.66	ft. per second
50 m.p.h. =	73.33	ft. per second
60 m.p.h. =	88.00	ft. per second
70 m.p.h. =	102.66	ft. per second
80 m.p.h. =	117.33	ft. per second
90 m.p.h. =	132.00	ft. per second
100 m.p.h. =	146.66	ft. per second

TO DETERMINE TRAIN SPEED. Modern heavy rails are 39 feet long. The number of rail joints over which the train passes in 26.6 seconds is the same as the train speed. For the lighter 33 foot rails, count the joints for 22.5 seconds. Use proportional time for other rail lengths.

The speed of a steam locomotive hauled train may be easily determined if the wheel diameter is known. This is from the number of exhausts per minute. Since there is usually one accentuated exhaust out of four, counting the number of these gives the number of wheel revolutions in a given time, from which speed may be calculated. Two tables give assisting data:

Wheel r.p.m. in 15 Seconds with 100-inch wheels	Corresponding m.p.h.*	If the Wheel Diameter in Inches is	M.p.h. is same as Wheel r.p.m. in
25	29.75		
30	35.70	30	5.37 seconds
35	41.65	35	6.26 seconds
40	47.60	40	7.16 seconds
45	53.55	45	8.05 seconds
50	59.50	50	8.95 seconds
55	65.45	55	9.84 seconds
60	71.40	60	10.74 seconds
65	77.35	65	11.63 seconds
70	83.30	70	12.53 seconds
75	89.25	75	13.42 seconds
80	95.20	80	14.32 seconds
85	101.15	85	15.21 seconds
90	107.10	90	16.11 seconds
95	113.05	95	17.00 seconds
100	119.00	100	17.90 seconds

*For other wheel diameters multiply these m.p.h. figures by: $\frac{\text{other diam.}}{100}$

TIMING A MEASURED MILE

1 Mile in	Equals	1 Mile in	Equals
30 seconds......	120.0 m.p.h.	95 seconds......	38.0 m.p.h.
35 seconds......	101.3 m.p.h.	100 seconds......	36.0 m.p.h.
40 seconds......	90.0 m.p.h.	105 seconds......	34.2 m.p.h.
45 seconds......	80.0 m.p.h.	110 seconds......	32.7 m.p.h.
50 seconds......	72.0 m.p.h.	115 seconds......	31.2 m.p.h.
55 seconds......	65.4 m.p.h.	120 seconds......	30.0 m.p.h.
60 seconds......	60.0 m.p.h.	125 seconds......	28.8 m.p.h.
65 seconds......	55.3 m.p.h.	130 seconds......	27.6 m.p.h.
70 seconds......	51.4 m.p.h.	135 seconds......	26.6 m.p.h.
75 seconds......	48.0 m.p.h.	140 seconds......	25.7 m.p.h.
80 seconds......	45.0 m.p.h.	145 seconds......	24.9 m.p.h.
85 seconds......	42.4 m.p.h.	150 seconds......	24.0 m.p.h.
90 seconds......	40.0 m.p.h.	155 seconds......	23.2 m.p.h.

MOTIVE POWER

TRACTIVE FORCE. The tractive force of a Diesel motive power unit is the combined forces acting at the rims of all drivers tending to propel the motive power unit and its train.

DRAWBAR PULL. The drawbar pull of any motive power unit is the tractive force less all of the forces required to propel the motive power unit itself. Because resistance values are different for each condition of grade and curve, drawbar pull may be an exceedingly variable figure for any speed and is, therefore, much less useful than tractive force data.

VALUES OF ADHESION. If two surfaces are pressed together, it requires force to slide one along the other. It has been found that there is usually a very definite relation between the force required to slide and the force between them. This ratio, $\frac{\text{sliding force}}{\text{pressing force}}$ is called the coefficient of friction (or adhesion) of the two.

Various tests have been made to determine the coefficient of friction (adhesion) between train wheels and steel rails, the force pressing the two together being the weight on the points of contact. The results have been so varied that most engineers hesitate to fix definite adhesive values. A consistent set of tests of a wide variety of electric locomotives over a long period of years show starting adhesive values varying from 48% downward. It has been

found, however, that on a clean, dry rail a factor of 35% is usually obtainable at start and a factor of 25% is normal on a wet rail if sand is used. However, as the train speed rises the movement of trucks and cabs, low spots in the rails, and various other causes tend to reduce the weight on drivers momentarily and thereby allow driving wheels to slip. The maximum useful adhesive values, then, must be reduced as the train speed rises. Fig. 43 shows reasonable adhesive values for dry rails and for wet rails using sand.

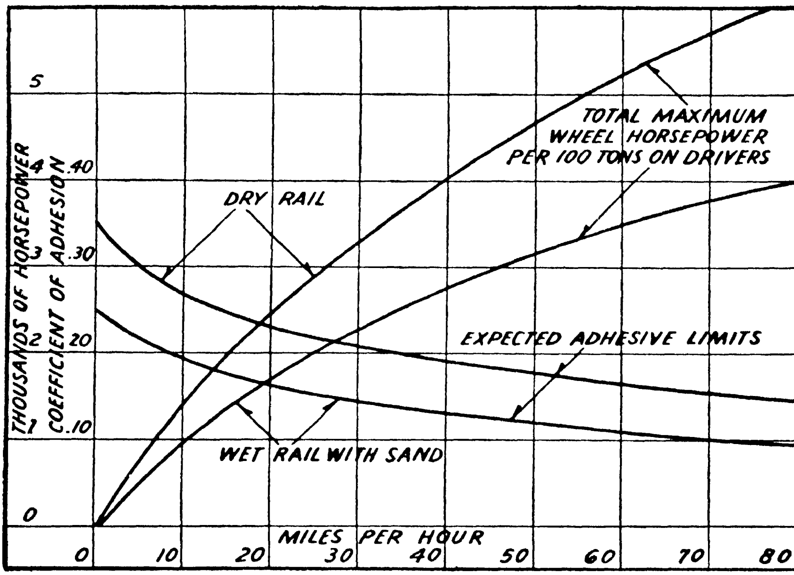


Fig. 43. Adhesion Factor Curves

MAXIMUM USEFUL HORSEPOWER FOR PROPULSION. Curves of adhesive values such as are shown by Fig. 43 automatically determine the maximum horsepower which may be expended at the driver rims for train propulsion. Since the adhesion is defined at a given speed, the horsepower is:

$$\text{Horsepower} = \frac{\text{Weight (pounds)} \times \text{adhesive factor} \times \text{m.p.h.}}{375}$$

$$= \frac{W \times A \times \text{m.p.h.}}{375}$$

For example, a pair of wheels loaded to 60,000 pounds on the rail, can utilize the following maximum horsepowers:

M.p.h.	Maximum Horsepower Dry Rail	Wet Rail	M.p.h.	Maximum Horsepower Dry Rail	Wet Rail
5........	238	157	25........	875	608
10........	428	304	30........	1000	692
15........	588	418	35........	1110	760
20........	735	520	40........	1210	830

For convenience, maximum horsepower curves for a locomotive having 100 tons weight on drivers are included in Fig. 43.

MAXIMUM TRACTIVE FORCE. The maximum tractive force which may be developed by any Diesel electric motive power unit (assuming that the electrical drive equipment design is suitably arranged) is determined by the weight on driving wheels and the coefficient of adhesion between the wheels and the rail. Steam motive power is usually designed to utilize less than 25 per cent adhesion (tractive force is less than 25 per cent of weight on drivers), whereas the electric motor drive with its smooth continuous torque permits (on the same basis) adhesive values of 30 per cent or better. Thus, with 100 tons weight on drivers (200,000 lbs.), a steam locomotive is normally designed for less than 50,000 pounds maximum tractive force, while a Diesel unit may develop over 60,000 pounds.

WEIGHT TRANSFER. In starting a train, the pull at the drawbar, or the acceleration of the body of a locomotive or railcar, or both, creates a "couple" or a turning force. For instance, assume a 2-axle locomotive with an 8 foot wheel base, both axles driven. If the center of the drawbar is 34½ inches above the rail and the tractive force and drawbar pull at start are each 10,000 pounds (neglecting locomotive resistance), the "couple" is 34½ inches x 10,000 pounds or 345,000 inch pounds. Since this must be balanced by a "couple" of equal value in the opposite direction, the tendency of the pull at the drawbar is to tip the locomotive over backward which acts to lift weight from the forward axle and transfer it to the rear axle, thereby creating the stabilizing "couple." The weight lifted from one and transferred to the other, then is:

$$\frac{345{,}000 \text{ in. lbs.}}{\text{the wheel base}} = \frac{345{,}000 \text{ in. lbs.}}{96 \text{ inches}} = 3{,}600 \text{ lbs.}$$

Similar weight transfer also occurs in swivel trucks with driving axles. The forward pair of wheels is relieved of weight and the rear

pair gains weight. While the ultimate distribution of weight on the various axles of a locomotive depends to some extent upon the height of truck centerpins, the size of centerplates, the method of driving the axles, etc., the weight transfer couples must still balance the drawbar-tractive force couples. A table showing maximum effect which may be expected is shown below:

100-TON 4-AXLE SWIVEL TRUCK LOCOMOTIVE—ALL AXLES DRIVEN. CENTER-PINS ASSUMED AT DRAWBAR HEIGHT

Worst Weight Conditions—Forward and Rear Axles of Each Truck

Locomotive	8′0″ Wheel Base		7′0″ Wheel Base	
T.F.	Forward	Rear	Forward	Rear
60000	39200	60800	37700	62300
55000	40100	59900	38725	61275
50000	41000	59000	39750	60250
45000	41900	58100	40775	59225
40000	42800	57200	41800	58200
35000	43700	56300	42825	57175
30000	44600	55400	43850	56150
25000	45500	54500	44875	55125
20000	46400	53600	45900	54100
15000	47300	52700	46925	53075
10000	48200	51800	47950	52050
0	50000	50000	50000	50000

From the table for the 8′0″ wheel base it may appear that if equal tractive force is applied to each axle of a 4-axle, 100-ton, swivel truck locomotive, a nominal 30 per cent adhesive factor for the locomotive (60,000 lbs. or 15,000 lbs. per axle) really may mean a 38.2 per cent adhesion on the leading axle of each truck:

$$\frac{15{,}000 \text{ lbs. T.F.}}{39{,}200 \text{ lbs. Wt.}} = 38.2 \text{ per cent adhesion}$$

Actually, however, when electric motors drive the axles, the motor weight is redistributed in the truck when the motors exert tractive force, so that the forward axle carries more of the motor weight. Therefore, the actual maximum adhesive factor is normally less than 35 per cent.

WEIGHT TRANSFER COMPENSATION. Recognizing that the transfer of weight from one axle to another of rail motive power is unavoidable, engineers have compensated for this on some cars and locomotives by an adjustment of the tractive force of individual motors during the early stages of acceleration. This is relatively

easy where two motors are connected in series for the start, since the shunting of one motor field will reduce its tractive force relative to that of the other motor. If, then, the two motors of one swivel truck or of a 2-motor locomotive are connected in series and the field of the leading motor is shunted, the tractive forces may be made approximately proportional to the weights on drivers. The position of the reverser automatically indicates which is the leading motor. The objections to this weight transfer compensation are that the motors are worked harder (operated at higher temperature), the equipment purchase price is increased, and additional control complication results.

HORSEPOWER DEVELOPED AT THE WHEELS.

Actual hp. required for propulsion = hp. at wheels =

$$\frac{\text{m.p.h.} \times \text{T.F.}}{375}$$

Actual hp. developed by each traction motor =

$$\frac{\text{m.p.h.} \times \text{T.F.}}{375 \times \text{No. of Motors}}$$

Engine hp. required for propulsion =

$$\frac{\text{Actual hp. (total) at wheels}}{\text{Transmission Efficiency}}$$

Total engine hp. required = hp. for propulsion + hp. for auxiliaries.

Fig. 44 shows the range of Diesel engine horsepowers which are normally applied to industrial and railroad switching locomotives. These represent the actual horsepowers which may be developed, not the nominal ratings sometimes applied by builders of the smaller sizes of Diesel engines.

CHARACTERISTIC CURVES OF DIESEL MOTIVE POWER.

The formula hp. $= \frac{\text{m.p.h.} \times \text{T.F.}}{375}$ represents a hyperbolic curve. Assuming no transmission losses, then, the maximum performance characteristic curve of Diesel motive power (using full available engine power at all times) is hyperbolic in shape. Because of unavoidable transmission losses, the actual performance curve is a hyperbola modified by the transmission efficiency, which varies slightly at different speeds and tractive forces.

The characteristic curve of Diesel electric motive power cannot be changed by changes in the type of motor, in gear ratio, or of wheel diameter, except as this may affect the efficiency of the drive. However, such a change in equipment, while not affecting the shape, may alter the unloading point up or down along the curve.

TRACTION MOTOR REVOLUTIONS PER MINUTE. For a traction motor geared to an axle:

$$\text{Motor r.p.m.} = \frac{336 \times \text{m.p.h.}}{\text{Wheel Diam. (inches)}} \times \text{Gear Ratio } \frac{(\text{Gear})}{(\text{Pinion})}$$

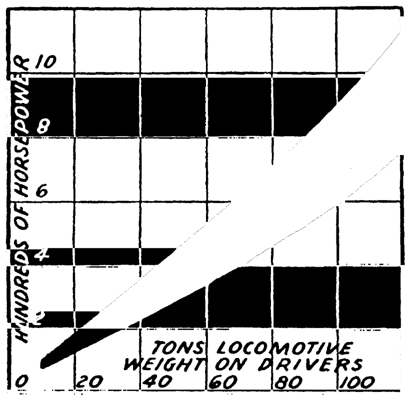


Fig. 44. Diesel Switcher Horsepower Ranges

COMPARISON OF TRACTION MOTORS. Since there is no fixed voltage for electric traction motors for Diesel motive power, motors may not be compared on an ampere or voltage basis. The following method is recommended:

(1) Select a gear ratio and wheel diameter for each so that they will have the same maximum safe m.p.h. and each will meet the standard gear clearance to the rail.

(2) Compare the continuous tractive forces (not amperes or voltage) with comparable gear ratio and wheel diameter.

To determine locomotive weight—find weight necessary to move one car up a given grade and multiply by number of cars.

Assumptions:

Car weight (tons)	25	45	60	75
Pounds resistance per ton	7	5	4	4
Locomotive adhesion	20%	20%	20%	20%

Example. To haul ten 60-ton cars up a 2% grade at 6 m.p.h. requires $7.5 \times 10 = 75$ tons on drivers (Fig. 45) and $80 \times 10 = 800$ Diesel engine hp. (Fig. 46).

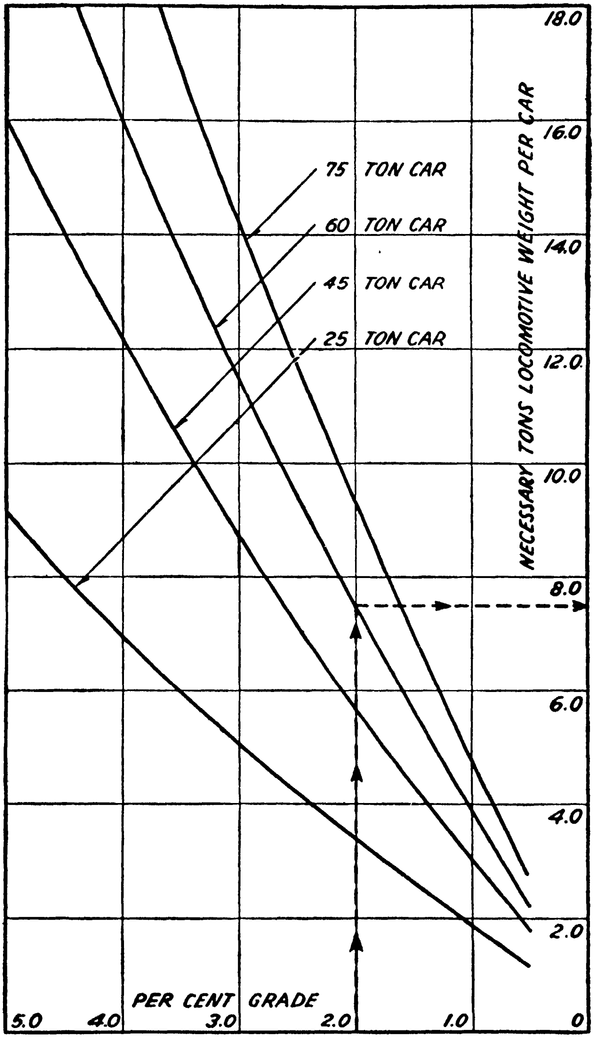


Fig. 45. Locomotive Selection Chart

DIESEL MOTIVE POWER APPLICATION

TO DETERMINE LOCOMOTIVE WEIGHT AND POWER. The weight of a Diesel locomotive is normally determined by the

worst pull which must be made at any time. The horsepower of the Diesel engine or engines is fixed by that combination of tractive force and necessary speed which results in the greatest power. In

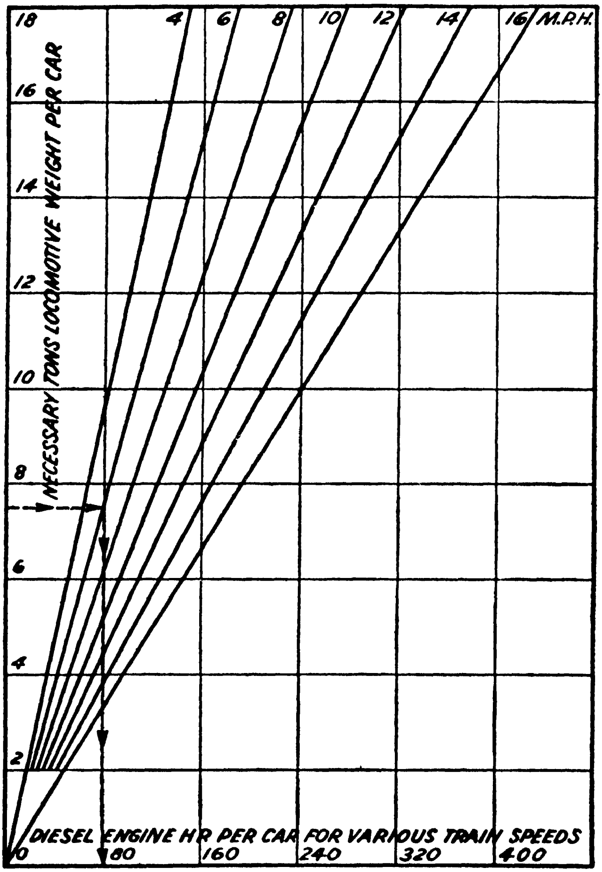


Fig. 46. Locomotive Selection Chart

determining these, operators often overestimate speed. Estimating 4 m.p.h. instead of 3 m.p.h. necessitates a 33 per cent increase in engine size, which may be very expensive.

Figs. 45 and 46 form an approximate guide for the selection of a Diesel locomotive. This is at 20 per cent adhesion, which results in heavier locomotives than some manufacturers like to apply. If higher adhesive values are deemed acceptable, find the weight and

power from the curve, then decrease the locomotive weight in proportion to the ratio of 20 per cent to the new adhesive value selected. If the service must be performed regardless of weather or rail conditions, it is preferable not to exceed the 20 per cent values chosen for the curves.

COMPARISON OF STEAM AND DIESEL PERFORMANCE. Diesel locomotives out-perform steam in switching service because more power may be applied to the wheels in the initial stages of an acceleration. Fig. 47 shows this clearly. Since area on this curve represents distance, it may be seen that the Diesel is far ahead 32 seconds after the start and from then on the steam locomotive must

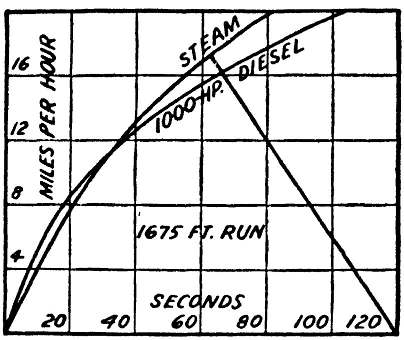


Fig. 47. Comparative Performance of 0-8-0 Steam and 1000 Hp. Diesel Switching Locomotives

gain speed in order to catch up. On all runs up to 1,675 feet the Diesel is the faster.

For long runs, the Diesel engine horsepower must more nearly approach the maximum steam horsepower or the steam unit has a definite advantage.

FUEL CONSUMPTION. If the steam locomotive fuel for a given switching service is known, the corresponding Diesel fuel may be estimated:

1 gal. Diesel fuel = 140 pounds of coal—light switching
1 gal. Diesel fuel = 120 pounds of coal—medium switching
1 gal. Diesel fuel = 110 pounds of coal—heavy switching
1 gal. Diesel fuel = 100 pounds of coal—transfer runs

For estimating where no previous fuel consumptions are known, Diesel fuel oil consumption may be taken as:

Light switching	.045 gal. per hour per ton on drivers
Heavy switching	.065 gal. per hour per ton on drivers
Transfer runs	.023 gal. per mile per ton on drivers

ESTIMATING GRADES. Stand on the track and estimate a point up the grade on a level with the eyes. Step off the distance to the point selected or count the rails. This gives distance and rise from which the per cent grade may be calculated. A bottle partly filled with liquid and held horizontally gives a water line which may serve as a rough level to estimate a point on the grade which is on a level with the eyes.

ESTIMATING DEGREE OR RADIUS OF TRACK CURVATURE. Draw a string from the outside rail across the curve to form a chord just tangent to the inside rail. Measure the gauge in feet and the length of the chord in feet. The radius of curve is then (all dimensions in feet):

$$R = \frac{\text{Chord}^2}{8 \times \text{Gauge}} = \frac{C^2}{8\,G}$$

The radius of a 1-degree curve is 5730 feet. The radius of a 2-degree curve is half that of a 1-degree curve, while a 3-degree curve is one-third of 5730 feet, etc.
Therefore:

$$\text{Radius of Curvature in feet} = \frac{5730}{\text{Degree of Curve}}$$

$$\text{Degree of Curve} = \frac{5730}{\text{Radius in feet}}$$

SWIVEL TRUCK OPERATION AROUND CURVES. Without widening of gauge, the sharpest curve which a truck with two axles can negotiate is:

$$\text{Radius in feet is} = \frac{\text{Wheel base in feet}}{K} = \frac{W}{K}.$$

$$\begin{aligned} K &= .234 \text{ for 20 to 24 inch wheels} \\ &= .214 \text{ for 25 to 30 inch wheels} \\ &= .180 \text{ for 31 to 40 inch wheels} \\ &= .160 \text{ for 41 to 50 inch wheels} \\ &= .150 \text{ for 51 to 60 inch wheels} \end{aligned}$$

These figures are based on M.C.B. standards for flanges and rails. Normally the overhang of the locomotive, the swing of the

coupler, and other considerations may determine the minimum radius of curvature which a locomotive may negotiate with a train.

ESTIMATING THE EQUIVALENT GRADE OF A RAILROAD. For ease in calculating the performance of Diesel motive power operating a train over a given profile, it is usually convenient to establish a figure for the average grade of the road which will permit calculations of averages rather than requiring a detailed calculation of each individual grade section. This average grade is normally known as the equivalent grade. In rolling country where there is no definite grade trend, the kinetic energy stored in a train when descending a grade is used to assist the Diesel motive power in carrying the train up the next grade. For this type of profile the equivalent grade may be estimated:

$$\text{Equiv. grade} = 100 \times \frac{(\text{sum of rises minus } \tfrac{1}{2} \text{ sum of falls})}{\text{Length of line}}$$

All figures being in feet.

For other types of profile, it may be necessary to break the run into sections, for each of which a definite grade trend and average grade figure may be established.

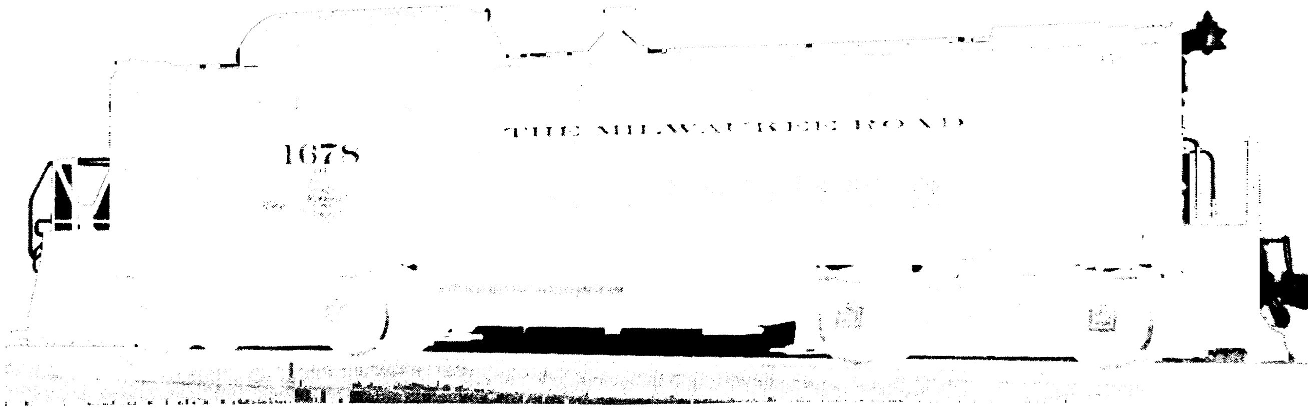
SAFE WHEEL LOAD ON TRACK. The approximate axle loadings permissible for different weights of rails are:

0 to 60 pound rail—500 pounds axle load per lb. of rail wt.
61 to 90 pound rail—600 pounds axle load per lb. of rail wt.
91 upward pound rail—700 pounds axle load per lb. of rail wt.

This assumes proper cross tie and ballast support.

CONVENIENT EQUIVALENTS

1 Kilowatt	= 1000 watts
1 Kilowatt	= 1.34 hp.
1 Kilowatt	= 44257 foot-pounds per minute
1 Kilowatt	= 56.87 B.t.u. per minute
1 Horsepower	= 746 watts
1 Horsepower	= 33000 foot-pounds per minute
1 Horsepower	= 42.41 B.t.u. per minute
1 B.t.u.	= 778 foot-pounds
1 B.t.u.	= 0.2930 watt-hours



1000 Horsepower Locomotive of The Milwaukee Road

Chapter VI

General Electric Light Weight Diesel Locomotive

FINGER-TIP CONTROL. Sitting up high, with an unobstructed view in both directions and with the controls grouped conveniently within arm's length, the engineer can spot cars quickly

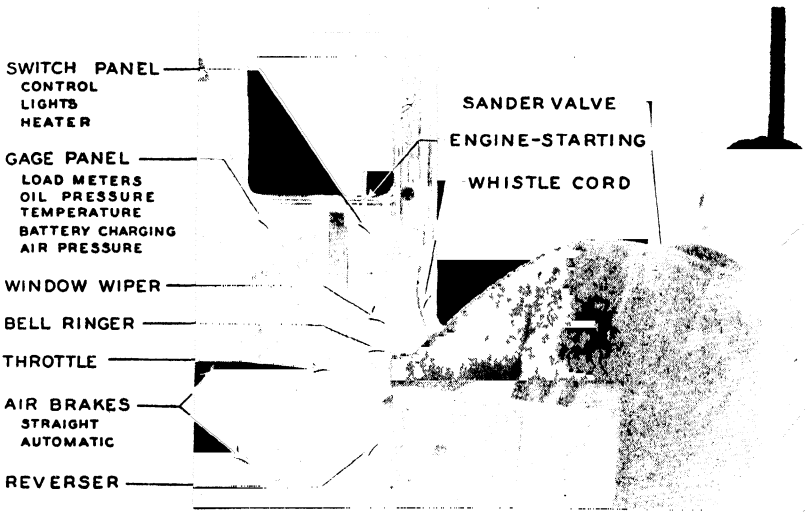


Fig. 1. Finger-Tip Control

and accurately. (See Fig. 1.) Moreover, the locomotive is easy to operate—you simply open the throttle and it responds instantly and accelerates quickly and smoothly. Reversing is equally as simple—just throw the reversing lever, with the throttle in the idling position.

HEAVY-DUTY GENERATOR. This modern traction generator, Fig. 2, gives the 65-tonner its smooth-operating characteristics. The doubly excited split field gives a generator characteristic that follows closely the Diesel-engine output. Thus, throttle response is quick and locomotive acceleration is both smooth and snappy.

Another important feature of this generator is its excellent

commutation. The commutator is carefully seasoned after assembly, and the brush rigging is of a special, simple design that gives the brushes unusual riding qualities. Exceptionally large inspection holes make the commutator and brush rigging readily accessible.

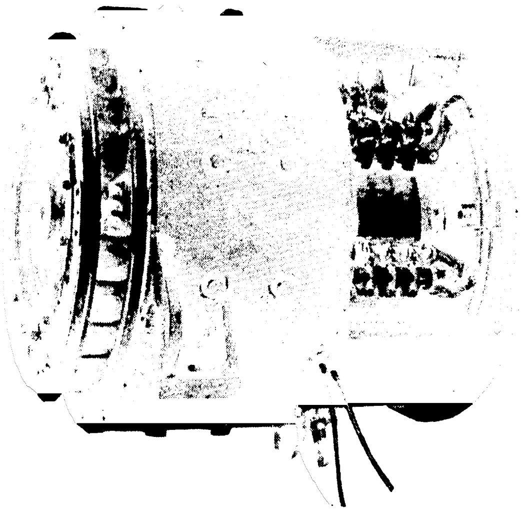


Fig. 2. G-E Direct-Current Traction Generator

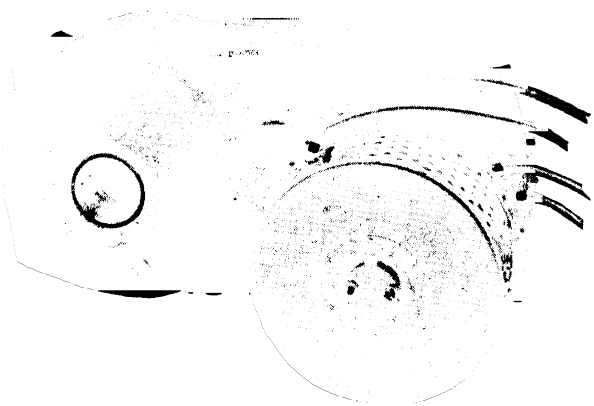


Fig. 3. G-E Direct-Current Railway Motor, Type GE-733, Complete with Double-Reduction Gears and Gear Box. End View.

The generator fan is mounted integrally with the flexible disk coupling and provides for multiple ventilation of the machine. One stream of air is drawn over the armature and between the field coils, and the other under the commutator and through the core.

MOTOR-GEAR UNIT. This powerful motor-gear unit, Fig. 3, is complete with double-reduction gears and gear box. The motor is insulated with Class B insulation. All gears are straddle-mounted and oil-lubricated. This sturdy, compact unit is built to withstand the hard usage and heavy loads encountered in railroad service, but limits maximum speed to 30 m.p.h. and slightly decreases the overload capacity.

SINGLE-REDUCTION DRIVE. This is the same type of single-reduction, box frame traction motor that is used so success-

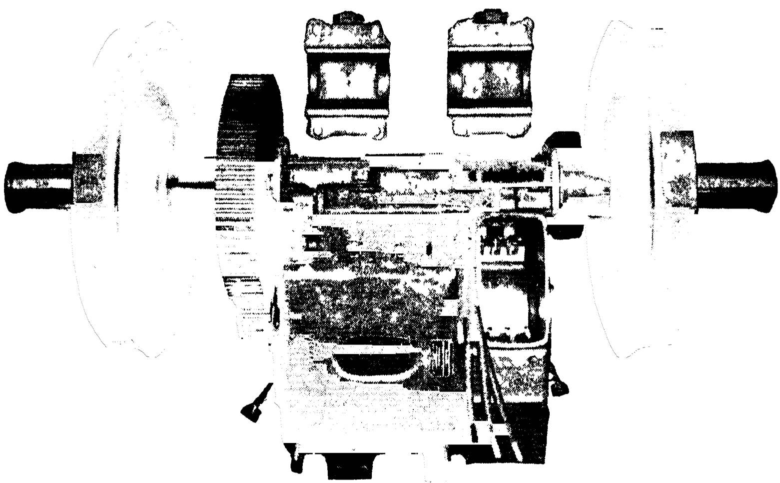


Fig. 4. G-E Direct-Current Traction Motor, Type GHM-838-D1, Mounted on Axle with Bearing Cap Removed

fully on big electric and Diesel-electric railroad locomotives. (See Fig. 4.) It has a high-torque characteristic and large thermal capacity to absorb the overloads encountered in industrial switching. It has waste-packed, split-type axle mounting and through-bolt axle caps, and bar-type spring-nose suspension. The strong, two-piece, fabricated gear case is sealed against the entrance of foreign material and loss of lubricant.

Class B insulation is used throughout. The armature has large-capacity antifriction bearings and labyrinth seals at both ends. The armature shaft is made from heat-treated alloy steel which has low deflection. This maintains good gear mesh and uniform loading on the pinion.

Large holes for inspecting the commutator are provided in the top and bottom, making the brush rigging readily accessible.

ONE THROTTLE OPERATES BOTH POWER PLANTS. The power circuits—which are simple—are shown below. The per-

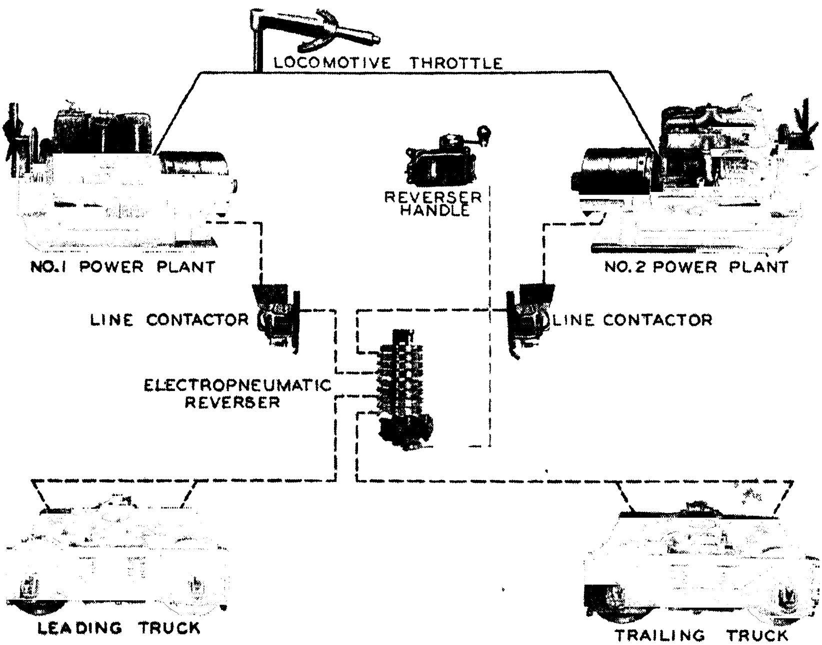


Fig. 5. Showing Power Plants and Power Circuits Which Operate the Trucks of G-E Locomotives

formance of the locomotive is the same in either direction of operation. Each power plant drives one truck and operates independently of the other, except that both are controlled by one throttle. Normally, the two power plants share the trailing load equally; but in an emergency one power plant will operate the locomotive at half its rated capacity. (See Fig. 5.)

The electric controls for this switcher are quite simple, and their operation is completely automatic. They require only periodic attention, and are standard, time-tested devices that any plant electrician can service readily.

Chapter VII

Baldwin–Westinghouse Equipment for Switching Locomotives

ESSENTIAL ELEMENTS. The Diesel Electric equipment consists essentially of two elements:

(a) A Diesel engine-generator unit power plant to supply the power.

(b) Electrical apparatus to transmit the power from the engine to the driving axles.

The electrical drive provides an effective means of transmitting the power from the engine to the driving wheels.

ELECTRICAL APPARATUS. The electrical equipment comprises standard railway apparatus adapted to meet the particular requirements for this class of service.

The electrical energy is supplied by a generating unit which consists of a main generator directly connected to the engine and an exciter-auxiliary generator unit belt-driven from the main generator shaft. The current generated by the main generator is transmitted through various switching and control devices to operate the axle-hung traction motors, which are geared to the driving axles and perform the actual duty of propelling the train.

The main generator is operated as a motor to start the engine when connected to the storage battery through its series starting field. The starting circuits are controlled by magnetic contactors which are operated from the starting push button.

The auxiliary generator is regulated for constant voltage, and supplies power for charging the storage battery which in turn operates the electrical auxiliaries. Main generator excitation is obtained from the exciter which is of the differential control type for automatic engine loading.

The lighting and control circuits are energized from the storage battery, being independent of locomotive or engine speed, and they are conveniently controlled from the operator's compartment.

The speed and direction of motion of the locomotive are controlled by a mechanical throttle in conjunction with a master controller through the operation of various switching devices which are grouped together in the cabinet.

The starting and control contactors, and those employed in the auxiliary apparatus circuits, are actuated by electromagnets, while the power (unit) switches and reverser in the traction motor circuit are operated by electro-pneumatic valves, utilizing compressed air.

On the meter and gauge panel is mounted the load ammeter.

GENERATING EQUIPMENT AND CONTROL DEVICES.

Main Generator. The main generator is driven by the engine and supplies current for the operation of the traction motors during running periods; it is also used as a motor, operating from battery current, to start the engine. (Refer to Fig. 37.)

Auxiliary Generator. The auxiliary generator furnishes current for battery charging during operating periods.

The Exciter. This furnishes excitation for the main generator.

Engine Starting Contactors. Magnetic contactors *G1* and *G2* establish engine starting circuits from the battery to the main generator armature and series starting field.

Auxiliary Generator Field Contactor. Magnetic contactor *EF* controls the auxiliary generator and exciter field circuits. It remains closed during all operating periods under control of a push button.

Reverse-Current Relay and Contactor. This relay and contactor *A* controls the auxiliary generator battery charging for reverse-current protection. It closes the circuit when the auxiliary generator voltage reaches a predetermined value above battery voltage.

Voltage Regulator. The regulator controls the auxiliary generator voltage by varying the value of field current in the field circuit.

Main Generator Field Contactor. Magnetic contactor *GF* controls resistance to reduce the main generator excitation during idling periods.

Voltage Relays. Relays *FS1, FS2,* and *FS3* operate at a predetermined generator voltage to automatically control the shunt field motor connections.

Engine Load Regulator (If Used). Carbonstat *LR* is hydraulically operated by a valve attached to the engine governor to prevent engine overload.

TRACTION MOTOR AND SWITCHING DEVICES. Traction Motors. The traction motors are geared to the driving axles. They are forced ventilated.

Electro-Pneumatic Switches. Switches *P1* and *P2* connect the traction motors to the generator.

Main Circuit Shunt and Ammeter. These provide meter indication of the main generator load current.

Motor Cut-Out Switches. These knife blade type switches control the operation of the electro-pneumatic power switches *P1* and *P2*.

Controller. The controller controls the direction of motion of the locomotive. It contains a locking device which prevents movement when the throttle is open.

Push Button Boxes. These are assembled units of push buttons used for controlling the various auxiliary and lighting circuits. The control push button box is provided with a lock.

Battery Circuit Shunt and Ammeter. These provide indication of the battery charge and discharge current.

Battery Cut-Out Switch. This knife blade switch controls the connection from the battery to all locomotive circuits, except operating cab light and electrical apparatus compartment.

Throttle Switch. The throttle switch, operated by the mechanical throttle lever, controls the contactor and power switch circuits when changing from idling to running position.

SEQUENCE TEST OF CONTROL EQUIPMENT. In order to test the correct functioning of each switch, contactor, and relay, and to determine if the operation of the unit is in proper sequence with other units, the following outline is given. (Refer to Fig. 37.)

(A) Preliminary

1. At battery cut-out switch disconnect wire *B* running to the terminal board stud *B*. At battery ammeter shunt disconnect wire *AG—* running to terminal board stud *AG—*.

2. Connect temporary wire between terminal *B1* on battery cut-out switch and terminal board stud *B*.

3. Connect temporary wire between terminal *N1* on battery cut-out switch and terminal board stud *N*.

4. Tie battery cut-out switch in the open position so that it cannot be closed.

5. Connect shop air line to the main reservoir.

(B) Engine Starting Circuits

1. Press control push button.

2. Press engine start button and note that contactors *G1* and *G2* close.

3. Pressing engine start button, close contactor *EF* by hand and note that switches *G1* and *G2* drop out.

4. Repeat the above with contactor *GF*.

5. When releasing either contactor *EF* or *GF* switches *G1* and *G2* should close again.

6. Still holding starting button closed, throw reverser switch handle to forward or reverser position and notch out with throttle.

7. Release starting button.

8. Note that *G1* and *G2* contactors drop out first and afterward observe *P1*, *F2* and *GF* closing.

9. Return throttle switch to idle position and note that *P1*, *P2* and *GF* drop out.

10. Press fuel pump push button and note that fuel transfer pump starts.

(C) Exciter Circuits

1. Press exciter field push button and note that contactoı *EF* closes.

(D) Locomotive Operating Circuits

1. Throw reverse lever to forward position.

2. Move throttle away from idle position. Reverser should be in forward position when left-hand magnet valve is energized. After reverser has been thrown to forward position note that switches *P1*, *P2* and *GF* close.

3. Return throttle to idle position. Move reverser handle to reverse position. Move throttle away from idling position. Observe if reverser throws to reverse position and if contactors *P1*, *P2* and *GF* close.

4. Press engine start button and note that contactors *G1* and *G2* do not close.

5. Open No. 1 motor cut-out switch and note that switch *P1* opens.

6. Close No. 1 motor cut-out switch, open No. 2 motor cut-out switch and note that switch *P2* opens.

7. Close No. 2 motor cut-out switch, close field shunting relay *FS1* by hand and note that contactors *M1* and *M2* close.

8. Holding *FS1* closed, then close field shunting relay *FS2* by hand and note that contactors *M3* and *M4* close.

8A. On 1000 Hp. locomotives holding *FS1* and *FS2* closed, close *FS3* and note that contactors *M5,* and *M6* close.

9. Holding *FS1* and *FS2* closed, close field shunting relay *FS3* and note that contactor *M5* and *M6* close.

10. Release field shunting relays, move throttle to idle position, and note that switches *M1, M2, M3, M4, M5, M6, P1, P2* and *GF* open.

11. Complete test by opening all switches.

(E) Generator and Traction Motors

1. Disconnect field shunting relay circuits by disconnecting:

(a) At switch *P2,* wire *G+* running to field shunting relay.

(b) At load ammeter, shunt, wire *NN* running to field shunting relay.

2. Disconnect meter wire by disconnecting wires *AM3* and *AM4* at load ammeter shunt.

3. Apply 1000 volts for one minute to *NN* wire, and note that there is no breakdown.

PERFORMANCE. The approximate performance of the locomotive is indicated by the curves shown in Figs. 1 and 2.

The performance curves include the motor current; the current demand on the main generator may be determined by a load ammeter, and by referring to the curve marked "Miles Per Hour," Fig. 1, the operator can determine the approximate speed at which the car or locomotive should be traveling, if the equipment is in good shape and properly adjusted.

The propelling force (tractive effort) which is exerted by the

traction motors at the rim of the driving wheels, is proportional to the current through the motors. The tractive effort developed at any load current may be determined, therefore, from the curves marked "Tractive Effort."

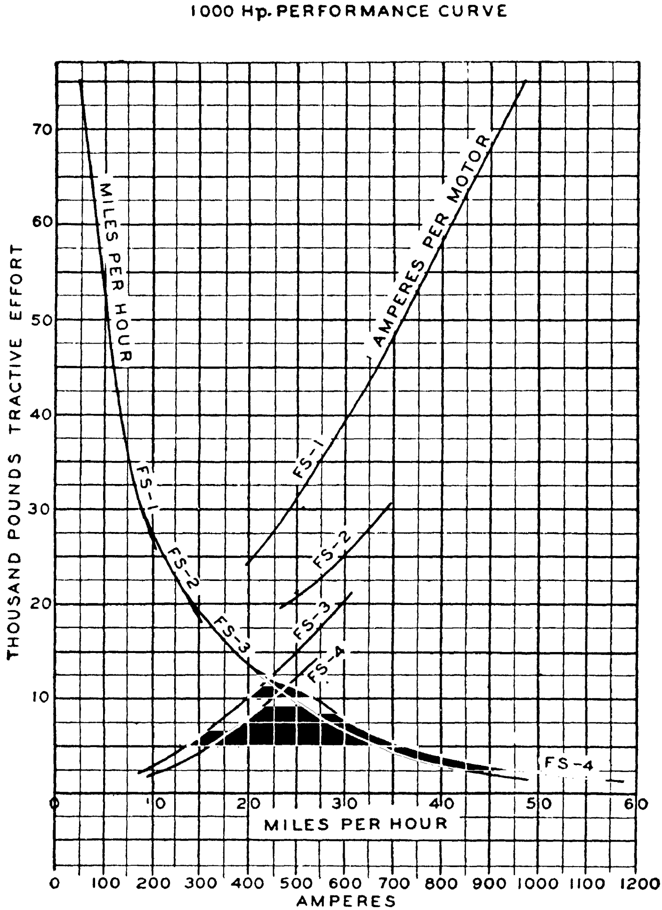


Fig. 1. 1000 Horsepower Performance Curve

The speed at which the locomotive will develop a given tractive effort, is dependent upon the voltage applied to the motors—a higher speed being obtained with a higher voltage.

The voltage at which the generator will deliver a given current to the motors is shown by the curve.

The engine which drives the generator unit to supply current to the motors is capable of delivering a given maximum horsepower; to prevent engine overloading, some provision must be made

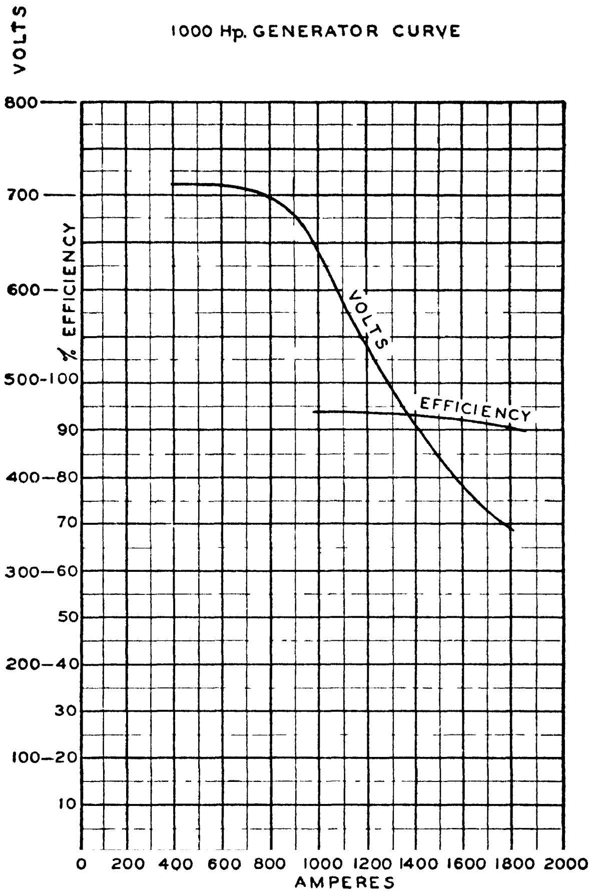


Fig. 2. 1000 Horsepower Generator Curve

for regulating the main generator voltage as the load current varies, to maintain practically a constant torque demand on the engine at its normal speed.

The inherent characteristic of the differential exciter automatically regulates the strength of the main generator field so that the generator voltage is decreased as the current demand is increased and vice versa.

ANALYSIS OF ELECTRIC TROUBLES THAT ARE LIABLE TO OCCUR

The following analysis covers troubles that are liable to occur:

I. **The Lamps Will Not Light**

If the lamps will not light the most likely cause is that the fuse in the push button box is blown.

Check the fuse in the particular light circuit involved and replace if blown.

II. **The Fuel Pump Will Not Operate**

(A) Check fuse on the control push button. If blown replace with new fuse.

(B) Check the brushes on the fuel pump motor to see if they are stuck in the brush holders and are not making contact on the commutator. If this is the case sand and wipe brushes, until they slide freely in brush holder.

(C) Check the commutator to see if it needs cleaning. If this is the case sand and wipe clean.

III. **Battery Will Not Turn Engine When Engine Starting Button is Pressed**

(A) Check fuses on control push button and engine start button to see if they are blown.

(B) Check main contacts on contactors *G1* and *G2* to see if they require cleaning or replacement.

(C) Check interlock fingers on contactors *GF* and *EF* and note that they are clean and making good contacts with the contact posts.

(D) Check brushes and commutator on main generator to see if they need sanding and cleaning.

IV. **Engine Will Not Fire**

(A) Clean fuel oil filters at inlet to fuel oil transfer pump and on front end of Diesel engine.

(B) Check to see that emergency fuel shut off valve is not tripped.

V. **Auxiliary Generator Will Not Charge Battery When Exciter Push Button Switch Is Closed**

(A) Check fuse of exciter field push button to see that fuse is not blown.

(B) Check fingers of exciter field push button to see that they are clean and making good contact with the copper segment.

(C) Check main contacts of exciter contactor *EF* to see that they are clean and making good contact.

(D) Check battery charge fuse to see if it has blown.

(E) Check battery contactor A to see if the contacts are clean and making good contact. If contactor *A* does not close it will be necessary for the electrician to check battery charge contactor and reverse current relay to see that they are operating correctly.

(F) Check auxiliary generator shunt field circuit from *EF* contactor to voltage regulator to *AF* wire on generator and see if connections are tight and continuous.

VI. **Locomotive Will Not Start When Speed Handle Is Moved Away From Idle Position**

(A) Check the reverser to see if it throws into position agreeing with position of master controller reversing handle. If reverser does not throw check the following:

(1) Check all fingers on the master controller to see that they are clean and making good contact with drum segment.

(2) Check interlock fingers on contactor *G2* to see that they are clean and making good contact with contact posts.

(3) Check throttle switch to see if contacts are clean and making good contact.

(4) Check control air pressure to see that it is 70 pounds.

(B) If the reverser is operating correctly, the trouble may be due to switches *P1* and *P2* not closing.

(1) Check main contacts of switches *P1* and *P2* to see that they are clean and do not require replacement.

(2) Check all interlocks on the master controller to see that they are clean and making good contact.

(C) If the reverser and switches are operating correctly the trouble may be due to the generator field or the exciter.

(1) Check main generator field contactor *GF* to see that

it is closing correctly and that contacts are clean and making good contact.

(2) Check interlocks on switches *P1* and *P2* to see that they are clean and making good contact.

VII. **Locomotive Will Not Accelerate Beyond 20 Miles Per Hour With Speed Handle in Full Speed Position**

(A) Check all field shunting relays and see that all contacts are clean and making good contacts.

(B) Place reverser drum in off position and notch out on speed handle. As the Diesel engine accelerates, observe the closing of the field shunting relays, which should be in numerical sequence.

(C) If relays fail to close, the trouble may be due to loose terminals of wires *G+* and *NN*.

(1) Shut down engine.

(2) Check *G+* terminals at *G1* switch and all field shunting relays.

(3) Check *NN* wires on load ammeter shunt and all field shunting relays.

(D) If only one relay fails to close, the trouble may be due to loose wires on relay or coil.

(1) Check *G+* and *NN* wires on respective field shunting relay after engine is shut down and see if they are tight.

(2) Check connections to resistors on relays.

(E) Check to see that exciter belts are not slipping.

VIII. **Heater Switches Closed, But Heaters Will Not Heat Up**

(A) Heaters will not heat unless auxiliary generator is operating.

(B) Check each heater switch for visible indication of actual position of switch mechanism.

(C) The tripped indication on the face of switch reveals that either an overload or short circuit exists.

(D) Move switch handle first to the off position and then re-close breaker again. If breaker trips refrain from any further attempts to close the switch until the cause of the overload or short circuit is remedied.

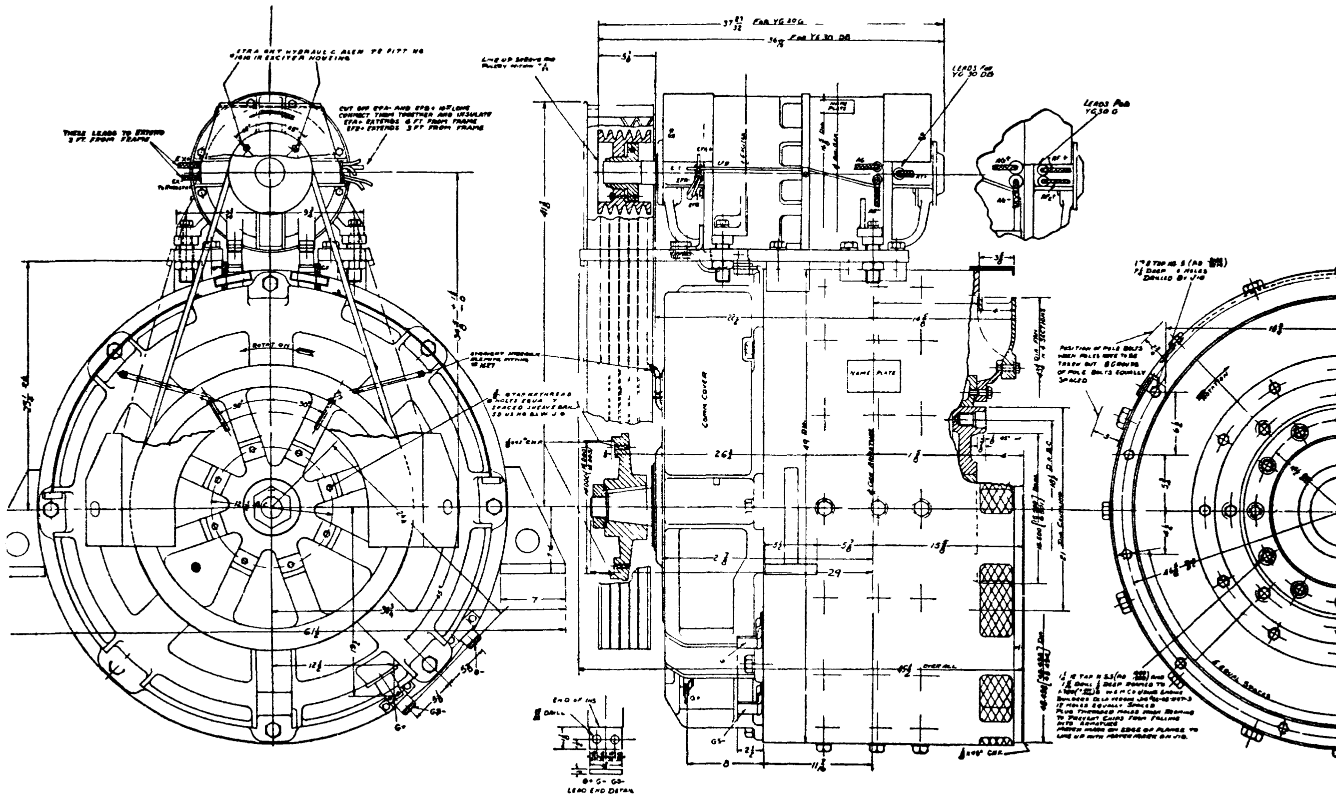


Fig. 3. Main and Auxiliary Generators

GENERATOR UNIT

The generator unit comprises that part of the equipment which is to generate the electrical current for operating the traction motors and auxiliaries. It consists of two machines known as the main generator and the exciter-auxiliary generator. The main generator

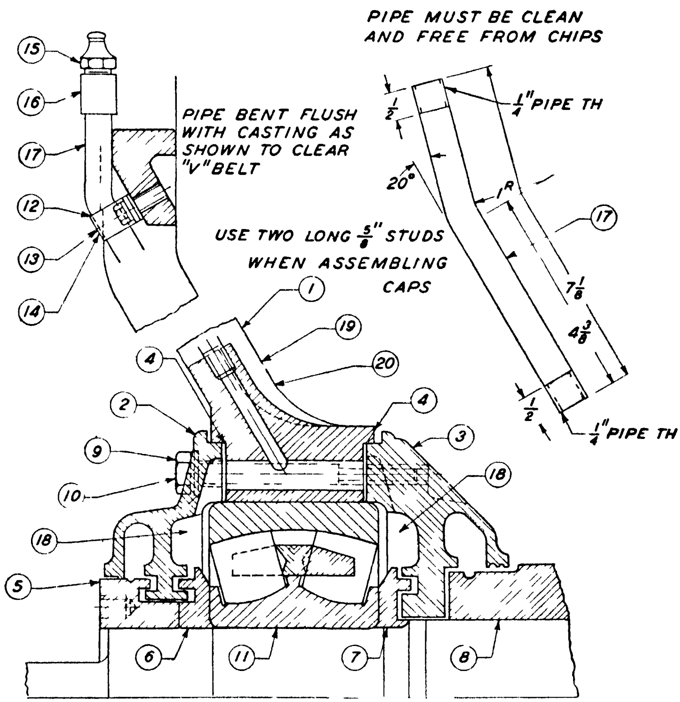


Fig 4. Main Generator Bearing Assembly

1 C E Housing
2 Outer Bearing Cap
3 Inner Bearing Cap
4 Gasket
5 Thrust Collar
6 Oil Slinger
7 Oil Slinger
8 Armature Spider
9 ⅝″—5½″ 16 Hexagon No Bolt
10 ⅝″ Lock Washer
11 150 M/M Free Roller Bearing
12 ″ x ⅝″ Hexagon Head S Bolt
13 ″ Lock Washer
14 Clip
15 ¼″ P T Straight Hydraulic Alemite Fitting
16 ¼″ B Coupling
17 7⅛″ of ¼″ X-Heavy B Pipe
18 50 oz of Grease
19 C E Housing
20 C E Housing

Note: Check Bearing Dimensions as per P D Specifications Min Internal Clearance .0025 after Assembly

armature is supported by a self-aligning roller bearing on the commutator end and the armature spider is solidly coupled to a flange on the engine shaft at the other end. The exciter-auxiliary generator

is mounted on top of the main generator and driven from the main generator shaft extension by vee belts and pulleys.

The main generator supplies the current for operating the traction motors and is separately excited from the low-voltage exciter which has a differential series field excited by line current of the main generator. The auxiliary generator supplies power to the auxiliaries such as lights, battery, etc. Its voltage is controlled by a voltage regulator.

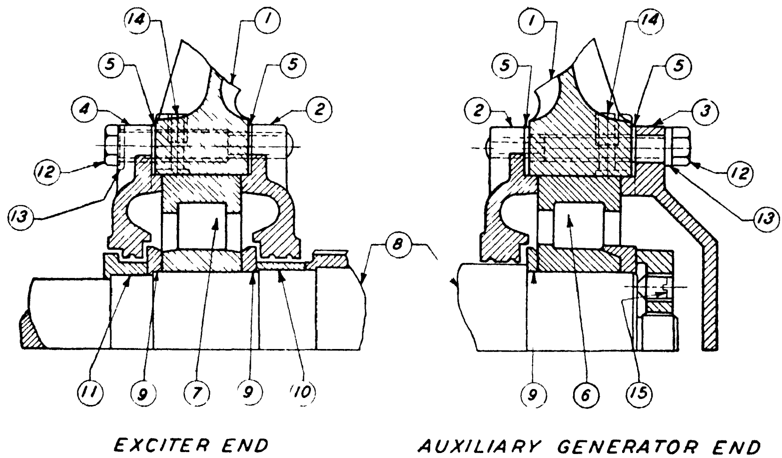
Ventilation is obtained by means of a fan mounted at the rear of the generator. It will draw air through the front (commutator) end housing and exhaust it at the rear.

Bearing and Lubrication. To insure continued operation, it is necessary to keep the bearing properly lubricated, and all dirt, grit, or other foreign matter must be excluded from contact with the bearing. The bearing is retained in the housing by means of an inner and outer bearing cap, and the grease lubricant is held in the bearing chamber around the bearing by these caps. To prevent leakage along the shaft, the sealing grooves in the bearing caps should be filled with manufacturer's grease.

There is danger of over-lubricating this bearing as well as under-lubricating it. The grease should be used in the Alemite fitting, about ½ oz. to each fitting, in order to feed grease to each side of the bearing. Add every three months, more or less, depending upon the service. On general overhaul the bearing caps should be thoroughly cleaned with gasoline and use of *dry* compressed air. The final cleaning of the bearings should be in clean gasoline after which the bearing should be blown by dry compressed air. If the bearing is not to be re-assembled immediately, it should be greased and wrapped in a protective covering to keep out dirt and moisture. In handling bearings, during overhaul, there should be a liberal use of clean lintless cloths for keeping both the hands and the bearings clean. Do not use waste on the bearings. Before re-assembling bearings they should be carefully inspected for: cracked races; cracked or pitted rollers; excessive wear of cage; and loose cage rivets.

When re-assembling the bearings, both bearing caps should be filled approximately half full and the space between rollers should

be packed with grease. After one month's operation add approximately 4 ounces of grease and thereafter follow regular greasing schedule.



TIGHTEN UP BEARING NUT UNTIL SOLID. THEN SCREW IN TWO OF NO. 15 OPPOSITE EACH OTHER. AFTER SET SCREWS HAVE BEEN TIGHTENED, STRIKE WITH HAMMER, AND TIGHTEN AGAIN BEFORE PEENING OVER.

NO	DISCRIPTION-MATERIAL-REFERENCE DRAWING
1	HOUSING
2	REAR BEARING CAP
3	AUXILIARY GENERATOR FRONT BEARING CAP
4	EXCITER FRONT BEARING CAP
5	GASKET
6	60^{MM} THRUST ROLLER BEARING
7	60^{MM} FREE ROLLER BEARING
8	SHAFT
9	THROWER
10	SPACER
11	DUST GUARD
12	$\frac{3}{8}'' \times 2\frac{1}{2}''$ HEX. HD. BOLT
13	$\frac{3}{8}''$ LOCK WASHER
14	ALEMITE HYDRAULIC FITTING
15	$\frac{3}{8}^{D}$-16TH $\times \frac{1}{2}''$ LONG CUP POINT
•	SAFETY-SET SCREW

Fig 5 Auxiliary Generator Exciter Bearing

Brushes and Brushholders. Information concerning the type and size of brushes for the individual generators, as well as the brush pressures, is given on the general data sheet in this section.

The brushes and brushholders should be inspected periodically to be sure that the presence of dirt or grit has not caused any of the brushes to stick in the brushholders, and that the proper brush pressure is maintained, since the wear on a brush reduces its length and, consequently, the spring tension. The brush tension can be regulated on the main generator by withdrawing the cotter pin that holds the tension barrel which holds each spring, turning tension barrel by inserting a ⅛″ diameter pin in one of the holes and turning sleeve until spring pressure is 2¾ to 3¼ pounds, then line-up one of the holes in the sleeve with the hole in the pin and insert cotter key.

All brushes that are chipped or worn excessively should be replaced. When fitting new brushes to a commutator, use sandpaper (not emery cloth) with the smooth side of the paper close to the commutator, to avoid rounding the brush edges, and draw it under the brush in the direction of rotation.

Brushholders are adjusted on a neutral position at the factory by rotating the commutator end bracket by means of the slotted bolt holes and doweling it in the correct position. The brushholders should be kept rigidly bolted in position to maintain ⅛-inch clearance between the bottom of the brushholders and the commutator. The pigtails on the brushes should be fastened securely under the screws provided for that purpose on the brushholder casting.

Commutator. The commutator surface should be polished and free from pitting. The mica between the copper segments is initially grooved or undercut to a depth of $\frac{3}{64}$ or $\frac{5}{64}$ inch; as the commutator wears, or if it is turned, the groove should be maintained since high mica will spoil the brush fit and cause sparking.

If the commutator becomes blackened or pitted, it should be cleaned with sandpaper (never emery), polished with fine sandpaper, and blown off with compressed air; the brushes should always be lifted when smoothing a commutator and not replaced until all grit has been removed. If the commutator is excessively worn or burned, the armature should be placed in a lathe and the commutator turned down just enough to give a uniform surface, after which the mica must be grooved with special saws. While

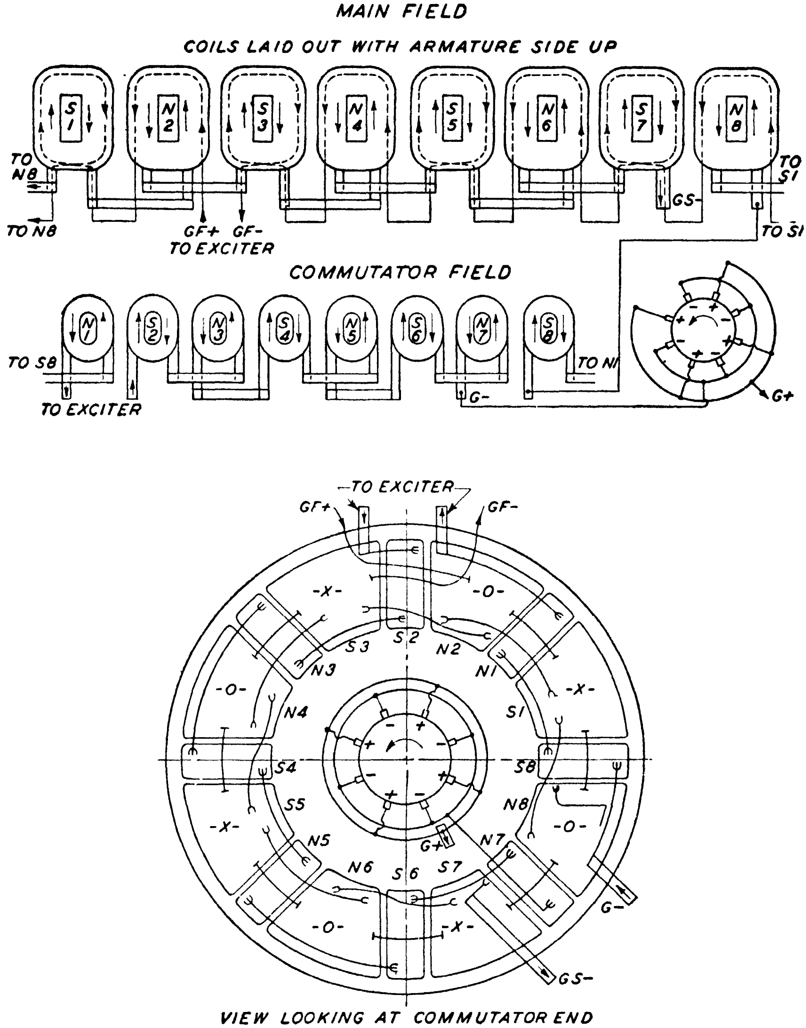


Fig. 6. Main Generator—Wiring Diagram

The style number of each coil is stamped on a tag attached to one end of coil. This tag is also stamped –O– (open coil) or –X– (crossed coil) following style number. The proper position of each coil in the frame is indicated by a tag shown below.

Polarity Test
N = North Pole S = South Pole

With a compass, check polarity of coils laid out on bench, also after assembling in frame. Use a resistor in circuit with coils to give sufficient direct current flowing as shown by arrows, to indicate polarity.

turning the commutator, protect the windings from flying copper chips; after undercutting, clean off burrs from copper segments, and clean out slots after smoothing commutator with 00 sandpaper.

Do not use any lubricant on the commutator as there is a certain amount of graphite in the brushes which supplies all the lubrication required.

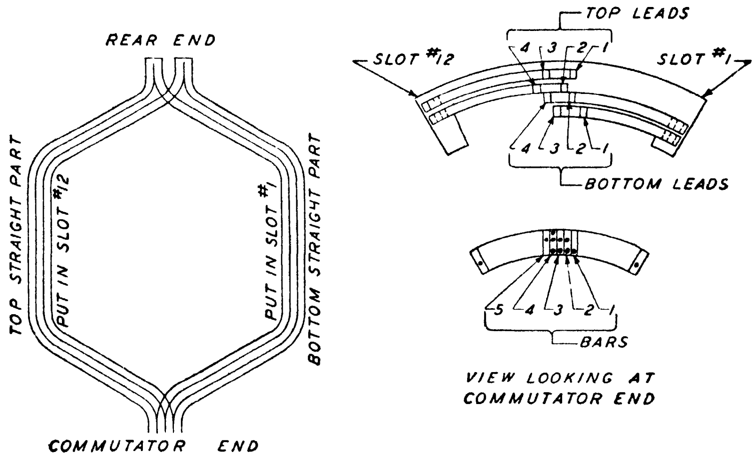


Fig 7 Main Generator Wiring Diagram

Laying Out Winding

1 ℄ of Tooth Between Slot 6 and 7 is on ℄ of Bar #3
2 Starting at Bar #3 Count Back (Clockwise) to Bar #1 and in This Bar Place Lead #1 from Bottom Leads of Starting Coil
3 Starting at Bar #1 Count Forwards (Counterclockwise) to Bar #2 and in This Bar Place Lead #1 from Top Leads of Starting Coil

Winding Data

Number of Armature Slots 92
Number of Commutator Bars 368
Coils in Slots 1-12
Leads Connect to Bars 1-2
Locates Top Leads of Starting Coil
Locates Bottom Leads of Starting Coil
Locates Starting Coil in Slots 1-12

Dismantling Main Generator and Exciter. In case it is necessary to make repairs to the armature, bearing, or field coils, the following procedure should be used.

To Remove Exciter—Auxiliary Generator. Disconnect all leads to exciter, lift brushes off commutator, remove vee belts and remove the bolts which hold the exciter frame in place. The machine may now be lifted off the generator. To disassemble exciter remove bolts that hold bearing caps and rotate caps approximately 30°. Then screw bolts in the three tapped holes and pull the dust guards from their fits. Next, loosen bolts at parting

line between the two halves of frame. The two frame halves may now be removed.

To Remove Roller Bearing. (a) First lift the brushes from commutator and disconnect strap connections between brush-holder and interpole coils.

(b) Remove bearing thrust collar with puller supplied for that purpose. Remove bolts that hold bearing cap and remove this cap.

(c) Remove bolts that hold end housing to frame and pull housing out of its *fit* by screwing bolts in the tapped holes provided. Before pulling the bracket from its fit, jack up under the armature shaft a sufficient amount to relieve the weight on the bearing. Support the main generator armature by strips of hard fiber (about 3 inches wide) between the armature laminations and poles and remove end jack. The commutator end bracket can be removed.

(d) Cover bearing with clean paper. Cut out paper to clear shaft and apply sufficient grease to have paper adhere to race.

(e) Remove bearing and both oil throwers by using a special puller, in conjunction with rear bearing cap.

(f) If a new bearing is to be installed, make certain that the outer race does not stick in the housing. If the outer race is tight then it is very important that the housing fit be scraped or lapped to give a loose fit having a clearance of from .001″ to .002″.

(g) When re-assembling an old bearing or installing a new bearing, the bearing, oil thrower, and thrust collar should be heated in an oil bath to a temperature of 125°C. for shrinking in place on the shaft. Refer to the bearing assembly when doing this.

To Remove Main Generator Armature. (a) To remove the main generator armature, the generator unit must first be removed from the locomotive; before uncoupling from the engine, fiber strips about 3″ wide should be carefully inserted into the air gap so that the armature will not drop down on the pole pieces when the generator is slid away from the engine crank shaft flange.

(b) With the generator unit removed, proceed as indicated in the preceding paragraph to remove the exciter, auxiliary generator, and the bearing assembly.

(c) An extension pipe will be required over the shaft at the

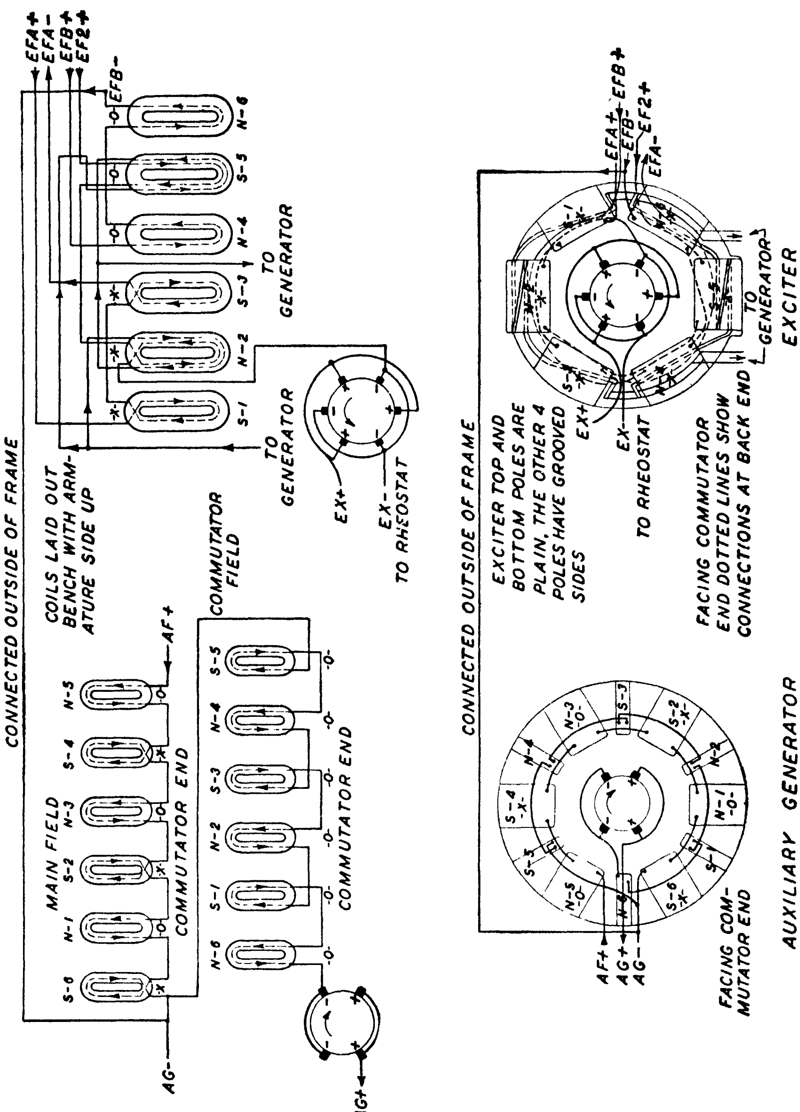
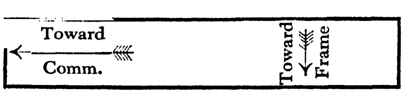


Fig. 8. Auxiliary Generator—Wiring Diagram

The style number of each coil is stamped on a tag attached to one side of coil. This tag is also stamped –X– (crossed coil) and –O– (open coil) immediately following the style number. The position of each coil in the frame is indicated by a tag shown below.



Polarity Test
N = North Pole S = South Pole

With a compass check polarity of coils laid out on bench also after assembled in frame use a resistor to give about 3 amps. current flowing as shown by arrows.

commutator end so that the armature may be protected far enough out of the frame to be handled entirely from the coupling end.

Caution: Before using an extension, screw on the shaft nut to protect the threaded portion of the shaft; do not allow the armature to rub on the poles when removed, and support the armature shaft on wooden blocks after removal.

(d) Pass a heavy rope around the ends of the armature shaft, and lift the armature just enough to clear the pole pieces, after removing any wedges, etc., and ease out of frame toward the coupling end. Care must be exercised not to injure the laminations and windings during this process.

INSTRUCTIONS FOR LINING UP SINGLE BEARING GENERATORS WITH SOLID COUPLINGS TO DIESEL ENGINE (TYPE 485 AND 487 GENERATORS)

(1) See that the mounting faces of the generator and engine, also the contact faces of the generator coupling flange and the engine coupling flange are clean with no burrs or rough spots.

(2) Carefully ream the bushing holes in the coupling faces and fit the bushings to the holes. The generator windings should be protected against entrance of any chips or cutting compound, if used.

(3) Check the coupling face of the engine coupling to make sure it is perpendicular to the axis of the crankshaft. This is best done by fixing a surface gauge rigidly to the engine bed-plate and recording the total eccentricity shown by the gauge on the coupling face in one complete revolution. The total eccentricity should not exceed .0005″.

(4) Support the armature on the lower main pole pieces by strips of fiber ⅛ inch thick, so placed that they can be withdrawn from the generator after it is assembled on the engine.

(5) Put two bolts, diametrically opposite to each other, in coupling and draw tight while pulling frame up to engine. Bolt frame to engine. Loosen the two coupling bolts and check alignment by using a feeler gauge at top, bottom and both sides of coupling faces. The feeler gauge measurements at the sides should not differ

more than .001 inch. The measurement at the top of the coupling should not be more than at the bottom. It is desirable to have the bottom measurement between the coupling flanges .001 inch greater than at the top, but this difference should not be greater than .002 inch. Any adjustments necessary may be made by shims between flange on frame and corresponding flange on engine. After the coupling line-up is correct, tighten all coupling bolts.

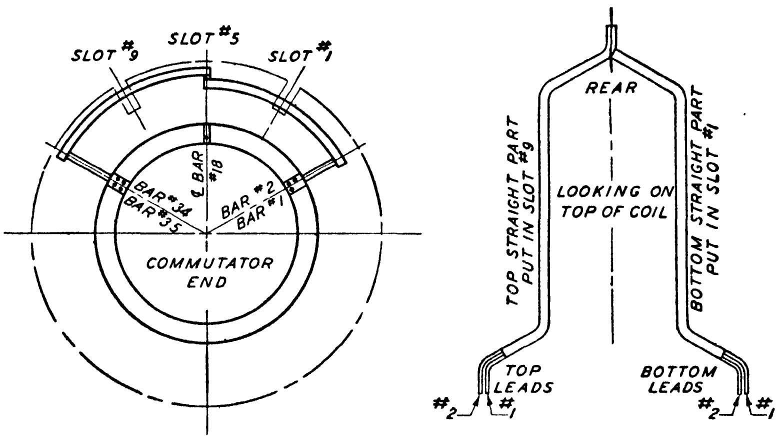


Fig. 9. Exciter Armature Wiring Diagram

Laying Off Windings

1 The Center Line of Starting Coil Is on Center Line of Slot #5 and on Center Line of Bar #18.

2 Starting at Bar #18 Count Back (Clockwise) to Bar #1 and in This Bar Place Lead #1 of Bottom Leads of Starting Coil.

3 Count from Bar #1 Forward (Counterclockwise) to Bar #34 and in This Bar Place Lead #1 of Top Leads of Starting Coil.

Winding Data

Number of Armature Slots = 49
Number of Commutator Bars = 98
Coils Lie in Slot #1 and #9
Leads Connect to Bar 1 and 34
Commutator Center Punched on End
:: Locates Top Leads of Starting Coil
:. Locates Bottom Lead of Starting Coil
. Locates Bar #18 on Center Line of Slot #5

(6) After the generator is coupled and bolted to the engine, be sure and remove the fibre strips that were used to separate the armature from the pole pieces.

TOOLS FOR GENERATOR UNIT

*Commutator Grinding Rig (without Stone) (for Main Generator)	S No. 1 133 179
*Grinding Stone for Commutator Grinding Rig	S No. 1 133 180
Bearing Puller (for Main Generator)	S No. 1 186 828

*Supplied only on Customer's Special Order.

Bearing Puller (for Exciter-Auxiliary Generator)........ S No. 1 168 821
Bearing Nut Wrench (for Exciter Auxiliary Generator)... S No. 1 116 363

†1¼" Socket Wrench American Standard size
†1" Socket Wrench American Standard size
†¾" Socket Wrench American Standard size
†⅝" Socket Wrench American Standard size
†½" Socket Wrench American Standard size
†⅜" Socket Wrench American Standard size
†¼" End Wrench

†These socket wrenches are not furnished. Note that the various sizes listed are American Standard which is different from U.S. Standard or S.A.E. Standard.

GENERATOR AND EXCITER—AUXILIARY GENERATOR 600 HP. GENERAL DATA

	Main Gen.	Aux. Gen.	Exciter
Operating Limits			
Maximum safe r.p.m.	900	2500	2500
Maximum volts	900	135	....
Maximum amperes	1600	85	100
Maximum shunt field amperes	100	6.5	6
Brushes			
Number of brush arms	8	4	6
Brushes per arm	2	1	1
Grade of brush	W-457	W-457	W-457
Size of brush inches	⅞x2¼x2¼	9/16x1x1¾	⅜x1x¾
	⅞x2½x2½	......	......
Minimum radial length of brush when worn	1¼"	⅞"	⅞"
Brush pressure	8 to 10 lbs.	2¼ to 2½ lbs.	
Air Gaps			
Main pole	.25 inch	.050 inch	.025 inch
Commutating	.375 inch	.094 inch	......

Reference Drawings

Outline (Fig. 3)
Bearing Assembly (Fig. 4)
Stator Wiring Diagram (Fig. 6)
Armature Winding Diagram (Fig. 7)

Weights

Generator	10,500 lbs.
Exciter-auxiliary generator	745 lbs.
Generator stator	5,270 lbs.
Generator armature	3,900 lbs.

GENERATOR AND EXCITER—AUXILIARY GENERATOR 1000 HP. GENERAL DATA

	Main Gen.	Aux. Gen.	Exciter
Operating Limits			
Maximum safe r.p.m.	900	2500	2500
Maximum volts	900	125	....
Maximum amperes	2000	85	100
Maximum shunt field amperes	100	6.5	6

Brushes

Number of brush arms	8	4	6
Brushes per arm	6	1	1
Grade of brush	W-457	W-457	W-457
Size of brush inches	.400x1.580x2¼	9/16x1x1¾	⅜x1x¾
Minimum radial length of brush when worn	1⅛″	⅞″	⅞″
Brush pressure	2¾ to 3¼ lbs.	2¼ to 2½ lbs.	

Air Gaps

Main pole	.25 inch	.050 inch	.025 inch
Commutating pole	.375 inch	.094 inch	......

Reference Drawings

Outline (Fig. 3)
Bearing Assembly (Fig. 4)
Stator Wiring Diagram (Fig. 6)
Armature Winding Diagram (Fig. 7)

Weights

Generator	10,500 lbs.
Exciter-auxiliary generator	745 lbs.
Generator stator	5,270 lbs.
Generator armature	3,900 lbs.

TRACTION MOTORS

The traction motors are of the same type as those in general use for electric traction service. They are known as Direct-Current Series Motors.

They are designated as Direct-Current because the electric current which operates them flows continuously in one direction.

They are called Series type because the operating current passes through the armature and field winding in series (i.e., first through one and then through the other).

One side of the motor is supported by bearings on the locomotive axle and the other side by a nose, which is cast on the motor frame, through springs to the truck transom.

Each motor is connected to its axle through single reduction gearing.

TRACTION MOTOR—GENERAL DATA

Weight

Motor complete, including gear and grease case	6170 lbs.
Frame, including poles, coils and brushholders	3130 lbs.
Armature	1650 lbs.
Gear case	170 lbs.
Gear	480 lbs.

Air Gap

Main pole	¼"
Commutating pole	5/16"

Brushes

Number of brush arms	4
Brushes per arm and grade	3 National AX-5
Size of brush	¾"x1¾"x2"
Brush tension	8 to 10 lbs.
Minimum radial length of carbon when worn	1¼"

Armature Bearing

Type	Roller bearing
Grade of grease	M-7280-1
Labyrinth seal grease	M-2694
Quantity of grease	Fill bearings full Fill caps ½ full

Reference Drawings

Outline	Fig. 16
Wiring Diagram Field	Fig. 17
Winding Diagram Armature	Fig. 18

Removing Traction Motors. (a) The leads from each motor are attached to the locomotive body by wooden cleats; remove these cleats and cut tape from the connectors. Disconnect all of the motor lead connectors taking care to see that all leads are plainly marked so that there will be no trouble when they are reconnected.

(b) Remove the truck center pin and disconnect the brake, sander and any other connections between the truck and cab. Jack the cab up at one end a sufficient amount to clear and run the truck out from under after first securely blocking other truck.

(c) Remove the bolt which secures the axle end of the gear case to the arm which is cast on the axle cap and also the bolt which secures the opposite end of the gear case to the lug on the motor frame. Pull out the gear case clips and the lower half of the gear case will then drop down and the upper half can be lifted off.

(d) Remove the axle shield, the motor axle cap bolts, and the motor axle caps.

(e) Remove the straps which hold the motor nose in place on the truck transom.

(f) Lift the motor out of the truck with a crane, hooking the lifting chains into the bales cast on the motor frame for that purpose. When hooking up the crane chains, if three chains are employed, care should be taken to so adjust the lengths that the

motor will be lifted first on the side next to the truck center, and rotated around the axle a sufficient amount so that the lower lip of the axle bearing housing will clear the axle, before the chain attached to the axle side of the motor takes up its slack.

Removing Armature from Traction Motors. (a) Remove pinion. (See section following on "Removing Pinions.")

(b) Remove all of the brushes and if they are in good shape so that they can be used again, mark each brush carefully so that it

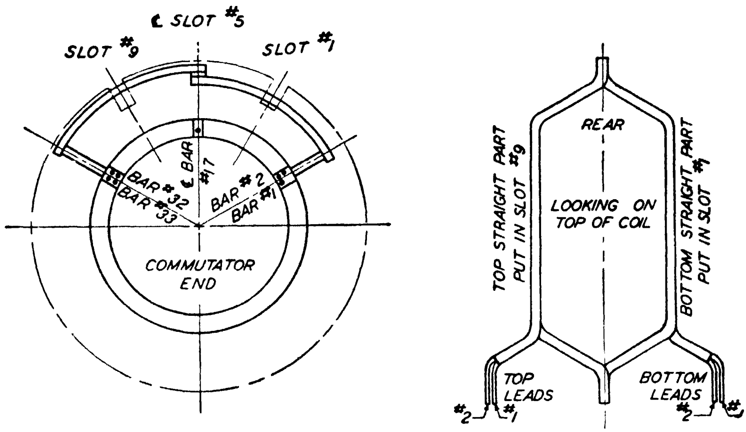


Fig. 10. Auxiliary Generator Armature Winding Diagram

Laying Off Windings

1 The Center Line of Starting Coil Is on Center Line of Slot #5 and on Center Line of Bar #17.

2 Starting at Bar #17 Count Back (Clockwise) to Bar #1 and in This Bar Place Lead #1 of Bottom Leads of Starting Coil.

3 Count from Bar #1 Forward (Counterclockwise) to Bar #32 and in This Bar Place Lead #1 of Top Leads of Starting Coil.

Winding Data

Number of Armature Slots = 47
Number of Commutator Bars = 94
Coils Lie in Slot #1 and 9
Leads Connect to Bar 1 and 32
Commutator Center Punched on End
:: Locates Top Leads of Starting Coil
:. Locates Bottom Lead of Starting Coil
. Locates Bar #17 on Center Line of Slot #5

can be replaced in the holder in the same position from which it was removed; this procedure will save reseating brushes when the armature is replaced.

(c) Pull pinion end bearing seal with special puller.

(d) Remove commutator end bearing cap.

(e) Remove set screw in nut.

(f) Remove nut and thrust collar.

(g) Remove pinion end bearing cap.

(h) Remove pinion end oil thrower by applying heat to oil thrower by means of a heated ring that will fit over shaft.

(i) Set the motor up on end with the commutator end down and remove the housing bolts on the pinion end. The housing can be loosened from its seat by screwing the jack bolts into the tapped holes which are provided for that purpose.

(j) Cover bearing with paper to keep out dirt.

(k) Screw the eye-bolt cap provided for that purpose on end of the armature shaft. The crane hook should then be attached to the eye-bolt and the armature together with the pinion end housing lifted straight up out of the motor frame. Care should be taken to see that the crane hoist is directly over the center of the motor before the lift is started and the armature should be carefully guided. When setting the armature down on the floor, care should be taken to see that it is properly supported so that it will not be damaged; it should be supported either from the shaft on two notched wooden blocks, or on a heavy felt or cloth pad. Be very careful when handling armature that no pressure is exerted on commutator.

(l) After bearing is removed again cover with paper.

TRACTION MOTOR BEARINGS. Since the successful performance of *roller bearings* depends to a very great extent upon the proper alignment of the various parts and the condition of the active surface, it follows that more care must be exercised in maintaining them than is necessary for sleeve bearings. Where sleeve bearings might operate satisfactorily despite the presence of a small amount of dirt, it is absolutely essential that roller bearings be kept positively clean. For this reason the bearing assemblies have been equipped with an elaborate arrangement of labyrinths to exclude dirt while in service. In compensation for this increased care, the application of roller bearings will require less frequent attention than sleeve bearings and will render more reliable service.

The general assembly of the commutator end, and the pinion end bearings, are shown on the bearing assembly drawing.

Lubrication of Armature Bearing. The selection of a proper lubricant is always important, and particularly so in the case of railway motor armature bearings, on account of the unusually severe

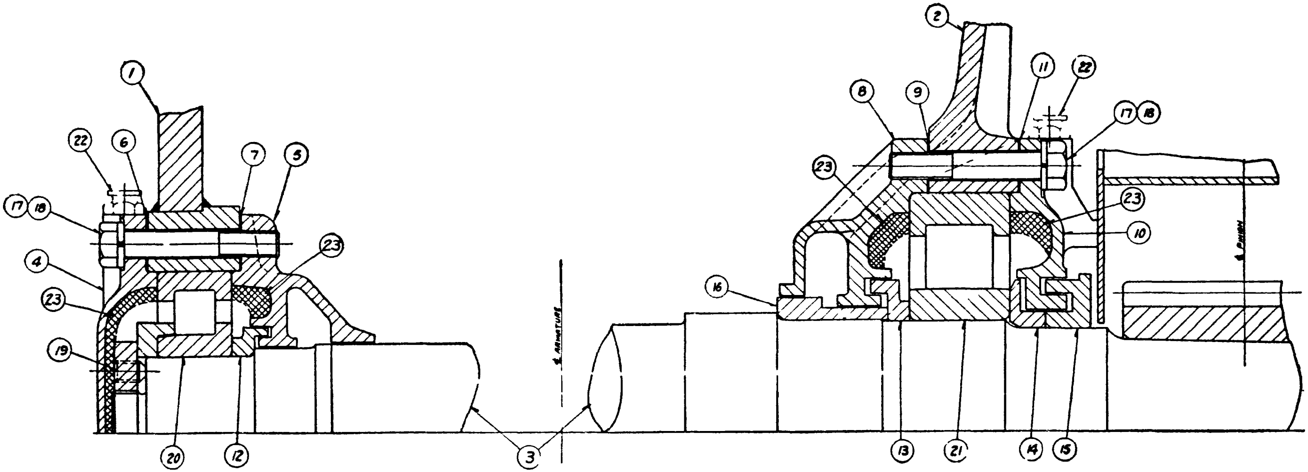


Fig 11 Traction Motor Bearing Assembly

1 Frame	7 Gasket	13 Oil Thrower	18 $\frac{5}{8}$ Lock Washer
2 P E Housing	8 P E Brg Cap	14 Oil Thrower	19 $\frac{1}{2}$—13x$\frac{5}{8}$ Cup Point Safety Set Sc
3 Shaft	9 Gasket	15 Oil Thrower	20 90 M/M Thrust Roller Brg
4 C E Brg Cap	10 P E Brg Cap	16 Oil Thrower	21 130 M/M Free Roller Brg
5 C E Brg Cap	11 Gasket	17 $\frac{5}{8}$—11x$3\frac{3}{4}$ Hex Hd S Bolt	22 ¾ Pt Heavy Duty Alemite Fitting Cat. #1396
6 Gasket	12 Oil Thrower		23 Grease M-7280-2

Tighten Up Bearing Nut Until Solid Then Screw in Two of Item 19 Opposite Each Other, After Set Screws Have Been Tightened Strike with Hammer and Tighten Again Before Peening Over

operating requirements. The grade of grease indicated on the data sheet is recommended by the bearing suppliers and it has been the experience that it will operate very satisfactorily in these bearings. It may be safely used during all seasons of the year.

The proper quantity of grease should be used. Part of this grease is placed on and between the rollers, the rest in the caps. It is also well to seal the labyrinth with grease when assembling the bearings. The correct grease best suited for this purpose is specified on the data sheet. The full quantities of grease should only be added after the bearings have been dismantled and cleaned. This should be done at overhaul or at least once every two years, thoroughly removing all old grease with gasoline. After the first month of service or 10,000 miles, four ounces of grease should be added to each bearing and thereafter approximately two ounces of grease should be added every 40,000 miles or every four months. The exact quantity of grease required must be determined by experience.

Fittings should be carefully cleaned before adding new grease to avoid forcing dirt into the bearing. All oil and grease cans should be kept covered when not being used.

To Inspect Condition of Bearings. The condition of the bearings at either end of the motor may be inspected with the armature assembled in the frame. The procedure is as follows: Commutator end; remove bearing cap nuts and bearing cap. Pinion end; remove pinion, bearing seal and bearing cap.

To Remove Bearings from Shaft. The armature should be removed from the frame (see section on removal of motor and armature). The bearings are pulled from the shaft by using the back bearing cap, the bearing cap studs and the special puller. On the commutator end the nut must be removed from the shaft before the bearing can be pulled.

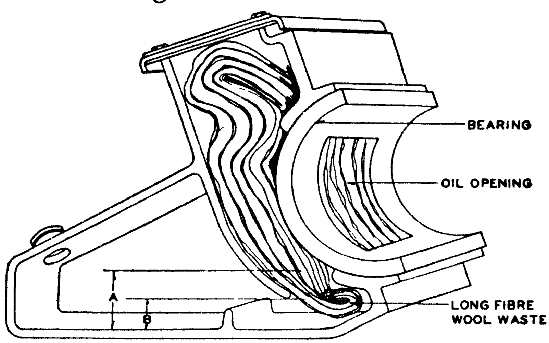
To Assemble Bearing on Shaft. To assemble the bearing races and throwers on the shaft, they should be heated in good clean oil, the throwers to about 150°C. and the races from 100 to 125°C. The throwers and races should be left in the oil long enough for the temperature to become uniform throughout. In applying the various parts to the shaft they should be pushed home and held in

position until seated. Great care should be taken that all races and throwers go on the same places from which they were removed, also that the races are not turned end for end.

Caution: Care should be exercised to use an oil with a safe flash point as a heating medium.

Note: This method of assembly can be used for reassembling other electrical apparatus anti-friction bearings.

AXLE BEARINGS. The axle bearings of the traction motors are arranged for oil and waste lubrication. Fig. 12 shows a section through an axle bearing.



A-NOR HEIGHT OF OIL IN OIL POCKET –3"
B-MIN HEIGHT OF OIL IN OIL POCKET –1½"

Fig. 12. Shows a Section through an Axle Bearing

Lubrication. In order to obtain satisfactory results with these bearings, it is important to use a suitable grade of waste, a good oil, and to pack the waste into the bearing in the proper manner. The waste should be long fiber wool. Before using, it should be saturated in oil for at least 24 hours, and left on a screen or grating to drain for several hours.

Mineral oil of a good grade should be used—Light oil in winter and heavy oil in summer. "Galena Electric Car Oil" or its equivalent is suggested.

(a) *Packing the bearings.* The proper packing of bearings is of the utmost importance as poor packing is responsible for a large percentage of hot bearings.

The axle caps must be packed before filling. As the periods between refilling and inspection are much longer than with the old

type of housings, care should be taken in packing the axle caps.

The oil is drawn up from the oil well to the bearing by the capillary attraction in the strands of waste and it is, therefore, essential for proper lubrication to provide a continuous path for the oil flow. This means that long strand wool waste must be used and that the waste must be in actual contact with the journal.

The first step in packing the bearing is too prepare wicks from a bunch of oiled waste. The pieces of packing required for the wicks for the bearings should be made into skein forms of sufficient length to reach from the bottom of the waste chamber up to about six inches above the seat for the waste chamber cover. The skeins should be twisted about one complete turn in order to hold all of the strands of yarn in place to produce a springy wick. As many skeins as possible should be packed in the waste chamber, starting at the inner end of the bearing and working outward. The upper ends of the skeins should be allowed to hang out over the seat of the cover about six inches or enough to hold them in place.

After the wick is formed in the chamber, it should be pressed over horizontally, tight against the axle, by means of a suitable packing iron, and held in place by forcing the necessary additional packing behind it. The loose upper ends of the skeins of the wick should then be folded over the other waste and tamped down tight.

A pad of saturated waste, large enough to fill the remainder of the waste chamber, should be placed on top of the wick to catch and hold dirt which might fall in when the bearing housing cover is opened.

After the bearing has been properly packed, the well should be filled with oil to the proper level.

(b) *Height of Oil.* The oil should be poured into the oil pocket and not on top of the waste. If too much oil is poured into the well it will overflow. The height of oil measured from the bottom of the chamber should be not less than 1½ inch nor more than 3½ inch.

Axle Bearing Clearance and Wear. New axle bearings are bored .028 to .030 inch larger than the axle over the center portion and .046 to .048 inch larger than the axle near the ends to give a relief bore.

The axle bearing seats in the motor are bored to size with a .017 inch shim between the caps and the frame in order to give a clamping fit.

When new bearings are installed, shims .010 to .012 inch thick, should be inserted between the axle cap and the motor frame. The axle caps should be driven in straight, as rocking will distort the splines and pinch the bearings. The radial clearance in the axle bearing should be at least .015 inch; after the locomotive has been in service long enough to wear the bearings in (generally about 50,000 miles) the shims are removed.

Wear in the axle bearings is not so serious as wear in the armature bearings, but it is good practice to renew axle bearings that show wear of 1/8 to 3/16 inch maximum. The amount of clearance can be measured by inserting a narrow feeler gauge between the under side of the axle and the bearing; the gauging can be done through the windows provided for that purpose in the axle shield. The end wear on each bearing should not be allowed to exceed a maximum of 1/4 inch. (When clasp type brakes are used, it may be necessary to limit wear on axle bearing adjacent to gear case to a lesser figure.)

Care should be exercised to see that the axle shields are in place and the dust guards are on at all times when the locomotive is in operation, as dust and grit in working into the bearings will greatly increase the wear of the bearings.

Removing Axle Bearings. In case it becomes necessary to remove the axle bearings while the motor is on the truck, proceed as follows:

(a) Run the locomotive over a pit if one is available, or locate it to the best advantage for working on the under side of the axle.

(b) Remove the axle dust shield between the axle bearings by taking out the four tap bolts which hold it in place.

(c) If the bearing to be removed is on the gear side, it will be necessary to take out the gear case bolts and clips, and drop the lower half of the gear case.

(d) Take out the four axle bearing cap bolts and remove the cap; if the cap sticks it can be loosened by tapping a flat cold chisel in the crack between the cap and the motor frame, first

on one side and then on the other side. Care should be taken to see that the cap is properly supported by a helper, or backed up by blocking when it is being loosened to prevent it from dropping suddenly and causing personal injury. The lower half of the axle bearing will drop down with the cap and can be readily knocked out with a wooden block and hammer. To remove the upper half of the bearing, jack up under the motor frame a sufficient amount to relieve the weight on the bearing and then revolve the upper half around the axle until it can be slipped off below. If the bearing sticks in the frame it can be knocked loose by driving down on the flange with a hammer and wooden block.

HOT BEARINGS. Hot bearings will occur occasionally and they are usually the result of one of the following causes:

(1) Lack of oil in bearings.
(2) Imperfectly packed bearings.
(3) New bearings with insufficient clearance.
(4) Grit or foreign substances working into the bearing.
(5) Motor nose clamped.
(6) Excessive end play in truck axles.

In case of trouble, investigate at once the level of oil in the well and make sure that it is up to the amount specified under the heading of "Lubrication." Examine the waste packing and make sure that it has not fallen away from the shaft. If it is not in proper shape, repack in accordance with instructions under the heading of "Lubrication."

In the case of new axle bearings, it is well to examine the clearance as bearings too tightly set up are frequently the cause of trouble. If the trouble persists with the bearing freshly packed, the oil at the right level, and ample clearances, the bearing should be removed and examined. If the bearing shows signs of cutting, it should be scraped down carefully to a new surface, or if too badly scored it should be replaced with a new bearing.

Before replacing a bearing which has been cutting, examine the journal carefully. Remove any roughness with fine emery paper, taking care after the operation to remove all traces of grit with a clean rag, and rub over the journal with oil. Grease should *not* be used on a journal which is lubricated by oil and waste, as the

grease will glaze over the waste surface and prevent the oil from reaching the bearing.

See that a new bearing is perfectly clean and rub a little oil over the surface before putting it in place.

Axle bearings should be set up with shims between the cap and frame if necessary to give the proper clearance. (See section on "Axle Bearing Clearance.") Repack with clean new waste and fill oil well to the proper level. (See section on "Lubrication.") The straps holding the motor nose should not be applied in such a manner that they produce a clamping action, as severe stresses in the nose and axle bearings may result. At least an inch clearance on each side of the nose is necessary to allow for the wear of truck parts.

APPLYING PINIONS. The pinions are not provided with keys and experience has shown that in order to obtain satisfactory operation, the pinions should be shrunk on the shaft.

The following points should be observed when the pinions are applied.

(a) The shaft and the pinion bore should be clean and free from burrs and swellings. (Clean with gasoline.)

(b) The fit of the pinion bore should be in contact with at least three quarters (75%) of the surface of the taper fit on the shaft. The contact area can be determined by rubbing Prussian blue, then red lead and oil, or thin lamp black and oil on the pinion bore and fitting it on the shaft.

(c) After checking the pinion fit, the shaft and bore should be wiped perfectly clean.

(d) To insure correct shrink fit, the pinions should be applied with an advance on shaft of 0.130 inch + or − 0.005 inch. The proper procedure to obtain this advance is as follows:

(1) Place the cold pinion on shaft with 1 inch overhang and then push pinion on by hand as far as possible.

(2) Measure overhang after operation number one.

(3) Remove pinion.

(4) After checking the above, the pinion should be heated in an electric oven or induction heater to 142° C. above room temperature for two hours, then remove and quickly wipe the bore dry

without allowing the pinion to cool. It should be pushed on the shaft by hand.

(5) Measure the overhang after operation number four above.

(6) The difference in measurements obtained between operations two and five indicate the advance.

(7) If the pinion advance is less than 0.125 inch, the pinion should be removed and reapplied.

REMOVING PINIONS. In order to remove a pinion, the motor must first be removed from the truck. The proper tool for removing a pinion is a pinion puller; there are a number of different types of pullers on the market and in a fully equipped repair shop, a power puller will probably be available.

On the special tool sheet of this section is listed a very simple form of puller which can be operated by one man and will meet with all the usual requirements; it consists of a split plate and ring, four stud bolts, and a head plate. After removing the pinion nut and lock washer, the two halves of the split plate are slipped back of the pinion and the retaining ring is placed around them.

The head plate is next slipped over the four studs and by tightening up on the nuts on the stud belts, the pinion is pulled off by the pressure exerted on the end of the shaft by the head plate. The nuts should be tightened alternately a little at a time and care should be exercised not to stand in front of the puller during the operation as the recoil when the pinion lets go may cause personal injury.

In removing worn pinions that are to be scrapped and are very hard to pull, the following schemes are sometimes used:

(1) The pinions are heated with a torch to expand the metal and relieve the fit. Note particularly that a flame should never be applied to a pinion which is to be put back in service as there is great danger of destroying the heat treatment. When an old pinion is heated, exercise great care to protect the shaft and housing from the heat to prevent damage.

(2) Pinions are loosened by placing a fuller (a blunt chisel-shaped tool) in the trough of the pinion and striking a series of heavy blows with a sledge; the operation should be repeated if necessary in a number of troughs around the pinion.

(3) In some extreme cases it is necessary to cut the pinion off by means of a heavy cold chisel and sledge.

Caution: Do not try to wedge the pinion off by using a drift.

TESTING DIRECTION OF ROTATION. On a locomotive, when the traction motor leads have been disconnected, the motors should always be tested for their direction of rotation when the motor circuits are established.

This test is very important and should be conducted carefully, as it is quite possible to have the locomotive apparently operate correctly in either direction and still have a wrong connection which would produce a serious motor trouble eventually.

For example, if a field and armature lead were interchanged, the motor would operate correctly when the locomotive was operating in one direction, but in the opposite direction the motor field could be cut out by the action of the reverser.

If the unit were put directly into service with all motors in operation without previously testing the individual motors, the condition mentioned above might continue for some time before it was detected, with the probable result of a roasted out motor.

The unit therefore should be moved backward and forward with each individual motor and should be operated in turn from each control station.

Watch the load ammeter during these tests, because if the car or locomotive is on level track the current required to move it in either direction with any one of the motors should be practically the same.

Any large difference in the current required to start the unit under the same conditions with the individual motors would indicate some abnormal condition.

The following combinations are the ones most likely to be encountered in making these tests:

(1) The individual motors operate the unit in the direction indicated by the reverse lever, and the current taken by individual motors when starting is practically the same, indicating the conditions to be correct.

(2) The individual motors operate the locomotive opposite the direction indicated by the reverse lever, and the current taken

by the individual motors is practically the same; this condition is caused generally by the interchange of the *F* and *R* wires between the reverse drum of the controller and the reverser. The condition may also be caused by the reversal of the armature or field loads of all the motors, but such a situation is very unlikely. Check with the wiring diagram and make the necessary correction.

(3) The individual axles do not revolve in the same direction for a given position of the reverse lever, but the current required to start is practically the same; such a situation indicates that the field or armature leads of one of the motors are reversed.

In the correcting of the difficulty, be sure that the change is made at the correct point—namely, do not reverse the armature leads when the field leads should have been changed and vice versa. A reversal of the wrong leads may correct the immediate difficulty, but it will also make the wiring different from the diagram and may lead to more troubles. Check diagram and change leads accordingly.

(4) A motor may operate the unit correctly in one direction but slowly or not at all in the other direction although the current is excessive. This trouble is usually caused by the interchanging of an armature and a field lead; such an arrangement will give correct connections for one position of the reverse lever, but it will cut the field out of circuit entirely in the opposite position.

REMOVING AND REPLACING FIELD COILS. In case one of the field coils has to be removed from a main motor, it will be necessary first to remove the motor from the truck.

Assuming the motor to be dismounted with the armature removed, proceed as follows:

(a) Lay the motor on its side upon two heavy stringers so that it can be rolled over conveniently into different positions.

(b) Strip the insulation off the leads from the coil to be removed to the adjacent coils, and unsolder the connections by the use of a blow-torch. Take care to protect the coils from the flame by pieces of asbestos sheet.

If one of the large main coils is to be removed, it will first be necessary to remove one of the small commutating coils on either side of it; therefore, in this case unsolder the connections to one of these adjacent coils also.

(c) Remove the nuts from the studs which hold the pole piece of the main coil which is to be removed, and lift out the pole. (See Fig. 13.)

(d) Remove the nuts from the studs of the adjacent commutating pole from which the leads have been unsoldered. Tap on the ends of the commutating pole studs with a hammer and a wooden block until the commutating pole projects enough from the coil so that it can be grasped and lifted out. (Fig. 14.) The commutating coil can then be taken out past the tip of the adjacent

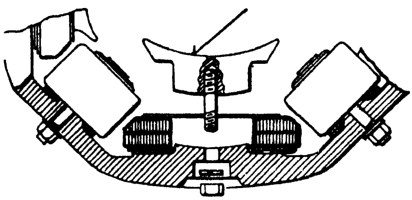


Fig. 13. Removing Main Pole

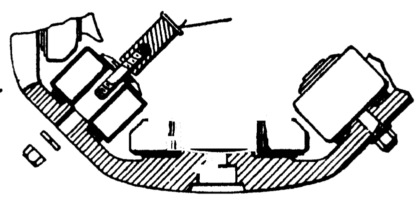


Fig. 14. Removing Commutating Pole

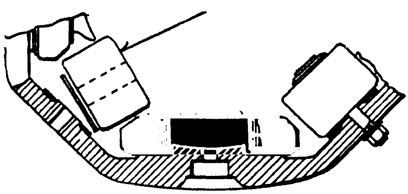


Fig. 15. Removing Commutating Pole Coil

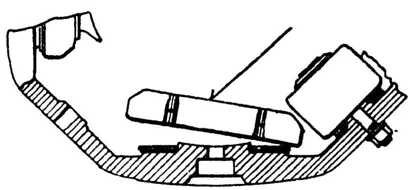


Fig. 16. Removing Main Field Coil

On some motors the main pole tip does not overlap the commutating field coil, and it is not necessary to remove the main pole to take off the commutating field coil.

pole by keeping close against the loose main coil. (See Fig. 15.) With the commutating coil removed, the main field coil can be swung out past the remaining commutating coil. (Fig. 16.)

If only a commutating coil is to be removed, it will be necessary in the case of motors having a main pole tip which overhangs the commutating coil, to remove an adjacent main field pole, but it will be unnecessary to remove the main coil or disturb its connections. The procedure is indicated in Figs. 13, 14, and 15.

When replacing coils, the procedure should be the reverse of that just described and the following points should be carefully noted:

(a) It is important that the main coil spring and main coil washer should be replaced in their original positions as on some

motors the spring and washer are placed back of the coil next to the frame, and on other motors in front of the coil next to the pole face. The main coil shield should be placed between the pole and coil.

(b) Be sure to place the commutating coil spring and commutating coil washer back of the commutating coil before putting it in place. Take care that these items do not slip in between the pole and its seat when it is bolted to frame.

(c) Make sure that the coils are turned right side up and right end to when placing them in position.

(d) See that the pole seats and backs are clean and free from chips before putting the poles in place, and make sure that the poles are pulled home to their seat by the stud bolts.

BRUSHHOLDER AND BRUSHES. The brushholders and brushes can be inspected when the commutator covers are removed. The size and grade of the brushes is specified on the motor "General Data" sheet.

Brush thickness is very important and the clearance of a new brush in the holder should be approximately .004 to .006 of an inch; if the clearance is much less, the carbon will tend to stick in the box, and if greater, the brush will rattle, wear away its sides and tend to chip and break. The width of a brush is not so important, as it may have as much as 1/16 inch clearance in the box without causing any trouble.

Brushes should be discarded when they have worn in length to such an extent that the brush pressure finger is within 1/4 inch of the end of its travel, or when the thickness has been reduced 1/32 inch maximum.

Brush pressure on the commutator is maintained by means of flat clock-type springs which exert pressure on a finger which rests on top of the brush. The brush pressure can be measured by attaching a small spring balance to the pressure finger directly over the brush, and pulling straight up in a line with the brush travel until the finger is just lifted clear of the brush. The pressure of the brushes can be checked in the above manner with the brushholder in place in the motor, with the exception of those on the axle side of the commutator where the pressure can only be judged by feel

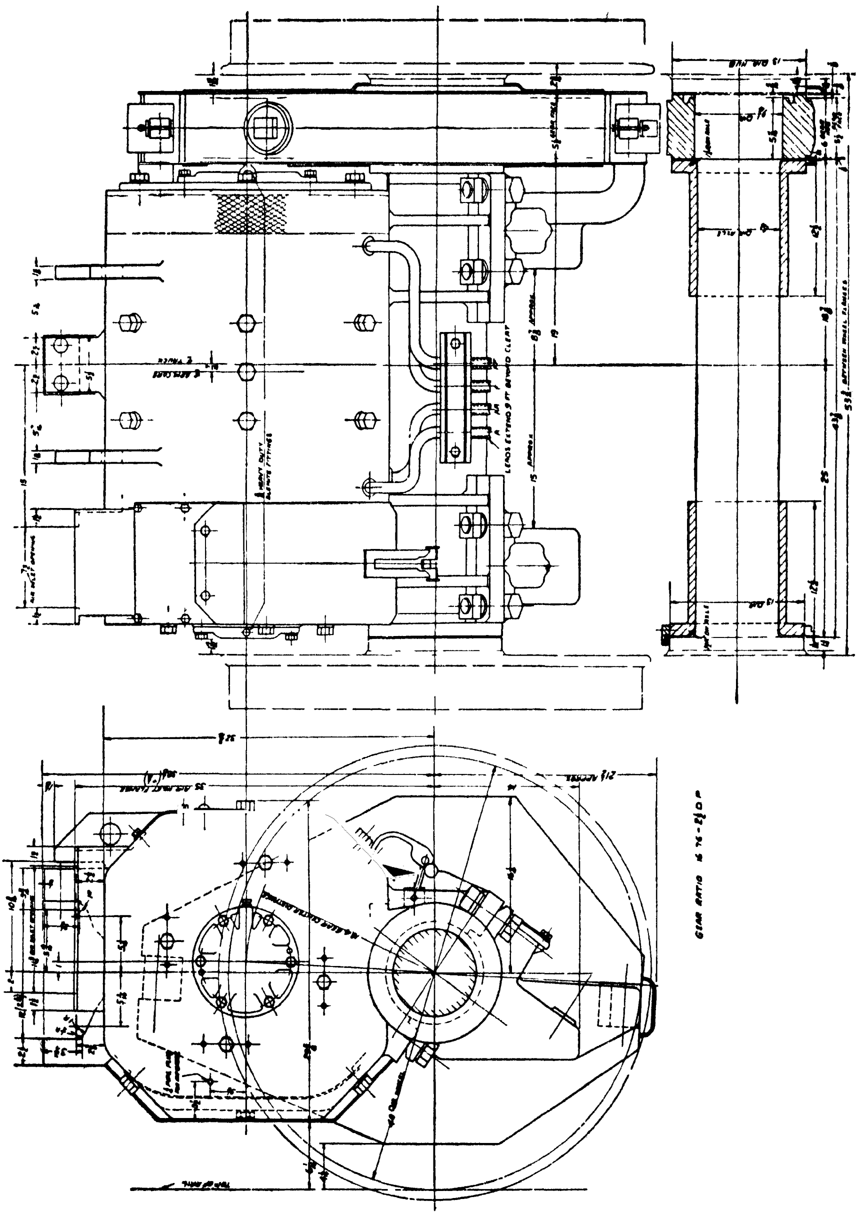


Fig. 17. Traction Motor Outline

with the holder in place. By checking the pressure in the top brushholder and comparing the feel of its tension with that of the lower holder, an approximation of the lower tensions can be obtained.

To remove the brushholder for renewal, or accurate adjustment of the brush pressure, first disconnect the cable lead from the holder by removing the tap bolts, then take off the nut and the top half of the mounting clamp, and the holder may be lifted out. The wrenches for use in this connection are listed at the end of this section under "Tools for Traction Motors."

The spring pressure is adjusted by removing the cotter pin from the tension barrel, turning the tension barrel in the proper direction to increase or decrease the tension, and re-inserting the cotter pin in one of the series of holes provided for that purpose.

The under side of the brushholder carbon box should be kept within ⅛ to $^3/_{16}$ inch of the commutator to reduce the chance of brush breakage. Adjustment is possible by loosening the nut on the clamping block stud bolt and moving the brushholder to the correct position; a fiber sheet of the proper thickness makes a handy gauge.

COMMUTATORS. A commutator which is taking on a polish and shows no signs of wear does not require any attention, but if it shows signs of roughness it should be smoothed; if only slightly roughened it can be smoothed with 00 sand paper but emery cloth or emery paper should never be used.

If the commutator is badly worn or burned, the armature should be removed and placed in a lathe, and the commutator turned just enough to give a uniform surface, after which the mica must be regrooved with special saws, swung on centers or bearings.

The mica insulation between the copper segments is grooved or under-cut initially to a depth of $^3/_{64}$ inch; as the commutator wears or if it is turned, the groove should be maintained since high mica will spoil the brush fit and cause sparking. The under-cutting can be done to the best advantage by use of one of the small power-driven saws which are built for this purpose. After the commutator has been turned or under-cut, the burrs which are formed on the edges of the bars during the process should be carefully removed with a three-cornered tool, the ends of the commutator bars rounded,

the slots cleaned out and the commutator finally polished with fine sand paper and blown off with compressed air. The brushes should always be lifted when smoothing a commutator in a motor and not replaced until all grit has been removed.

The leads from the armature winding are soldered into the ends (necks) of the commutator bars which should be carefully inspected when examining the armature. If the armature has been overheated and the solder thrown out, the leads should be resoldered.

Do not use any lubricant on the commutator as there is a certain amount of graphite in the brushes which supplies all the lubrication required.

TOOLS. The work of overhauling the traction motors is greatly facilitated by the use of suitable tools.

The following tools are furnished:

	Style
Roller bearing and shrink ring bearing	
C.E. bearing nut wrench	S No. 1 090 183
Pinion puller	S No. 1 090 180
Armature lifting nut with eye bolt	S No. 1 090 181

ELECTRO-PNEUMATIC SWITCHES

The unit switches are operated by compressed air and controlled by electro-pneumatic valves. In general, each switch comprises a stationary and a movable contact, an interlock assembly, an air cylinder for bringing the contacts together, a magnet valve for admitting air to the cylinder, arc shields for protecting the metal portions of the switch, and a blowout coil for extinguishing the arc which is formed when the contacts are opened while current is flowing through them.

(a) **Contacts.** The stationary (upper) and moving (lower) contacts are made of hard-drawn copper of sufficient cross section to give long life and are identically the same. Each contact is held in place by a tap bolt which has a slotted head so that it can be removed readily with a heavy screw driver.

Burning at opening and closing occurs only at the tips of the contacts and does not materially affect the current-carrying surfaces. The shape of the contacts and the mechanical action of the

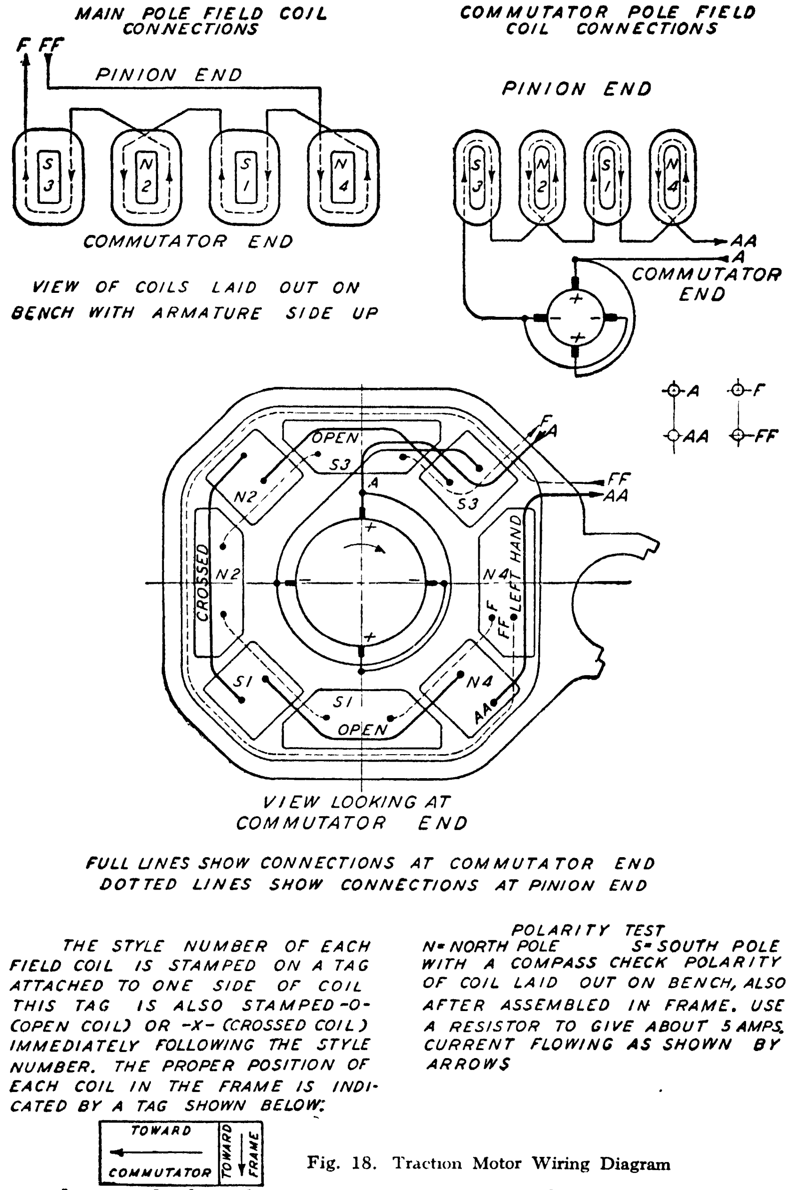


Fig. 18. Traction Motor Wiring Diagram

switch is such that the contact tips are brought together first, and they are then rolled back on each other through the action of a spring so that with the switch fully closed, the final contact occurs

at the rear portion or heel; when the switch is opened, the tips of the contacts separate last. The deep rolling action provided minimizes mechanical wear and the tendency to weld or freeze.

The contacts normally wear to a surface which will give the best contact without any attention; however, the contacts should be removed when they are worn or burned away to the extent that the current carrying surfaces are materially affected. If the contacts roughen in such a way that they catch and do not close to-

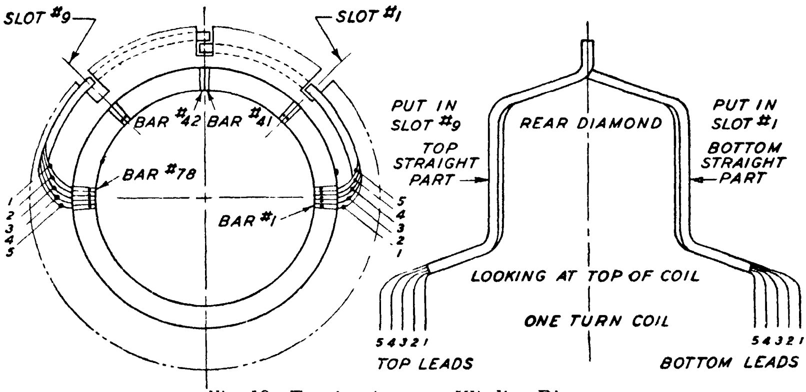


Fig. 19. Traction Armature Winding Diagram

Laying Off Winding

℄ coil on ℄ slot on ℄ mica between bars #41 and #42 starting at bar #41 count back (clockwise) to bar #1 and in this bar place lead #1 from bottom leads of starting coil. Count from bar #1 forward (Counter-clockwise) to bar #78 and in this bar place lead #1 from top leads of starting coil.

Winding Data

Armature has 31 slots. Commutator has 155 bars. Coil throw 1-9. Bar throw 1-78.
. . . . Locates top leads from starting coil. . . . . . Locates bottom leads from starting coil.
. . . Locates starting coil in slots #1 and #9.

gether at the heel, the contact tips should be smoothed with a file. With compressed air available, the contact action can be tested by pressing the pin in the magnet valve cap, taking care to have no current through the switch while experimenting.

The spring which causes the contacts to roll when they engage is readily accessible for inspection and renewal. In the fully closed position the lower contact bracket comes against a stop so that the finger spring does not carry the full thrust of the air cylinder. The spring should be examined from time to time to make sure that it is in good condition.

(b) **Air Cylinder Maintenance.** Pistons are properly oiled when the switches are assembled at the factory and ordinarily will

function for a long period (six months or a year) before they require any additional lubrication. When lubrication is necessary, oil as supplied by the manufacturer for this particular purpose, should

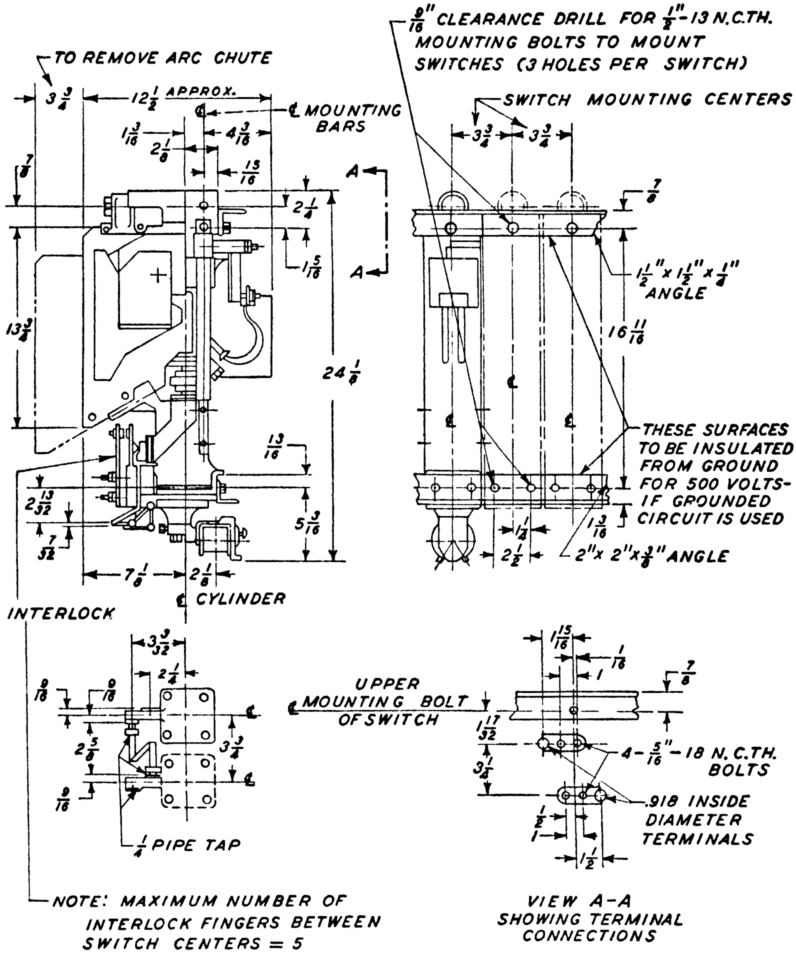


Fig. 20. Pneumatic Unit Switch Outline

be used. The use of unsuitable oil will lead to trouble from gummed pistons which will cause sluggish action or sticking.

Switches which operate sluggishly may have one of the following faults:

(1) Leaky piston packing. To check for a leaky piston, ener-

gize the magnet valve so as to close the switch and then apply a solution of soap and water around the vent hole in the cylinder top and around the piston rod guide; leakage past the piston will be indicated by bubbles. If the switch has been in service for a long time, the trouble may be due to a dried out piston, which generally can be remedied by squirting a small amount of oil in the cylinder vent hole and operating the switch a few times to work in the oil. If the piston does not stop leaking, remove and if in bad shape replace with a new one.

(2) A broken cylinder spring. If the piston spring is broken, the switch will close quickly but open slowly.

(3) The operating cylinder clogged with dirt. If its cylinder is dirty and gummed up, the switch will close and open slowly.

Pistons should be taken out at the general overhaul period and cleaned and oiled. To take out a piston, remove the four tap bolts from the cylinder cap and remove the cap and gasket. Next, take out the cotter pin in the end of the piston rod and remove the piston packing, and the follower washer will then be forced out by the piston spring.

All of the parts should be cleaned and inspected, and if the piston is badly worn it should be replaced with a new one; before replacing a piston, lubricate with oil. The cylinder walls should be wiped perfectly clean before re-assembling, and rubbed with a little oil. In replacing the cylinder head, be sure that the gasket placed between the cylinder and cap is in good condition.

The above remarks apply in general to the electro-pneumatic details applied to other apparatus.

(c) **Magnet Coil and Valve.** An electro-pneumatic valve is used to control the admission of compressed air to each operating cylinder. In order to operate the switch, it is only necessary to complete the circuit from the battery through the magnet coil; the current in the coil magnetizes the core which pulls the armature down to open the valve and admit air to the operating cylinder, at the same time closing the exhaust port from the cylinder to the atmosphere. When the coil is de-energized the valve lifts to shut off the supply to the cylinder and allows the cylinder to exhaust to the atmosphere.

For detailed information concerning valve inspection and maintenance, see the section following on "Control Magnet Valves."

To install a new magnet coil, disconnect the coil leads from the coil; take off the magnet cap and lift out the armature and valve stem; using the core wrench, unscrew the core and lift out. The coil may then be slid from the valve and replaced by a new coil.

In screwing the core back in place care should be taken to see that it is screwed in until it fits up against the bottom shoulder. In this position the core should be tight and the coil should be clamped firmly; if the coil is loose, add washers on top.

(d) **Arcing Horn and Arc Shield or Chute.** An arc horn is attached to each moving contact bracket to carry the arc away from the contact to the arcing space. When the arcing horn is burned off, it should be replaced at once with a new one.

The arc chute, which surrounds the main contacts, can be released readily and slid out from its position; it is provided for the purpose of directing the arc and preventing it from coming in contact with the blowout poles and other metal parts of the switch. The parts of the arc chute are all made of arc-resisting insulating material, but they will gradually wear away under the continual burning action of the arc and will require occasional renewing. The sides should be renewed before they have burned away sufficiently to expose the metal pole pieces.

The braided copper shunt which carries the current from the lower contact to the contactor terminal should be fastened securely and if broken or badly worn, it should be replaced promptly.

ELECTRO-PNEUMATIC REVERSER

The reverser functions to reverse the connections between the fields and armature of the traction motors and prescribe movement of the locomotive either forward or backward.

The reverser consists of a drum (with insulated copper segments) capable of rotation through a small angle, air cylinders with pistons for drum rotation, control magnet valves, power and control fingers and an insulating base.

To operate the reverser it is only necessary to complete the circuit from the battery through one of the magnet coils. The

current in the coil magnetizes the core to pull down the armature and open the valve, thus admitting air to one of the cylinders to turn the drum.

The reverser drum is divided into two parts; the larger section, which handles the main motor current, is provided with heavy copper segments which make contact with stationary fingers mounted at each side of the drum. The smaller section, which handles only the low-voltage control circuits, is provided with cam segments which close and open the small fingers on each side. The object of these interlock fingers, as they are called, is to prevent operation of the power switches until the drum is fully thrown in either direction.

A handle is provided on the end of the reverser shaft so that it can be operated by hand in cases of emergency or during inspection.

The interlocking of the control circuits with the reverser is such that the drum contacts do not break the motor current. Any sign of arcing on the drum indicates either weak finger pressure or faulty operation. The drum contacts should be kept clean and smooth with the aid of fine sandpaper. The contacts should be wiped perfectly clean after they are smoothed, and particular care should be exercised to see that no grit is lodged under the fingers.

Fingers. The pressure of the fingers on the contacts should be approximately 5 to 6 pounds for the main contacts. The interlock fingers when closed have approximately 1-pound pressure. The finger pressure can be measured by means of a small spring balance attached to a bent piece of metal strap which can be slipped under the finger.

If the segment under the fingers is to be cleaned, the fingers should not be lifted far enough off the drum surface so as to strain the spring and reduce the tension; such a common source of trouble should be carefully avoided.

If the contact fingers and drum segments are allowed to operate completely dry, they will start to cut in a comparatively short time. A little light machine oil should be spread occasionally over the drum contacts with a piece of cloth, and the drum should then be operated a few times; any surplus oil around the contacts or

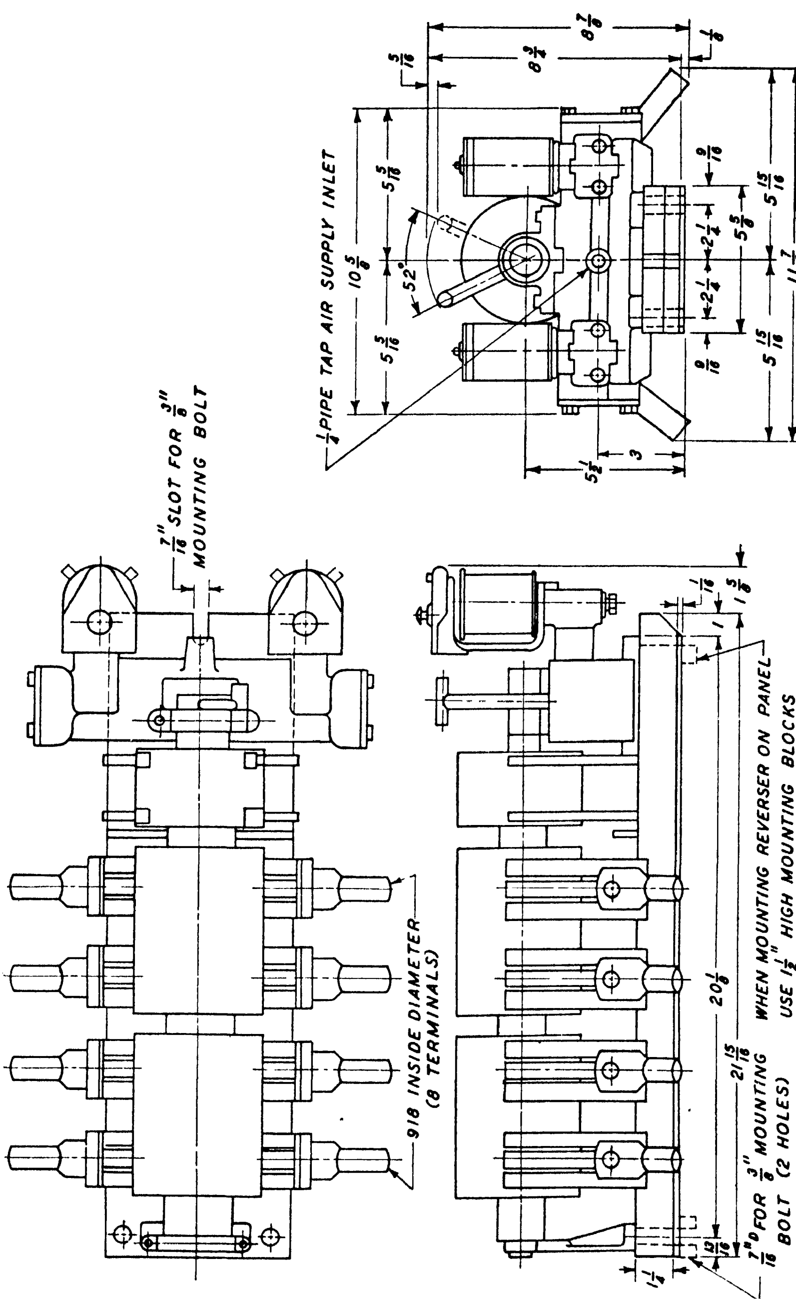


Fig. 21. Reverser Outline Drawing

segments should be wiped off. The drum bearings should be oiled at intervals with a light oil.

The finger pressure is varied by changing the bend in the finger springs where the flat spring type finger is used. To increase the pressure, it is necessary to remove the finger by removing the screws which hold it in place, and give the spring a little greater set. The fingers will maintain their pressure for a long period of time if they are not abused. Fingers of the compensated type cannot be adjusted for spring tension. A damaged finger must be replaced.

Cylinder Maintenance. Pistons are properly oiled when the reverser is assembled at the factory and ordinarily will function for a long period (six months or a year) before they require any additional lubrication. When lubrication is necessary, only oil as supplied by the manufacturer for this particular purpose, should be used. The use of unsuitable oil will lead to trouble from gummed pistons which will cause sluggish action or sticking.

In order to remove the piston rod and pistons, it is necessary to first remove the four tap bolts which hold the drum bearings in place and lift out the drum. Next, the tap bolts in each cylinder head should be taken out and the head removed, care being exercised not to injure the paper gaskets which are under them. The nut and lock washer on one end of the piston rod should now be removed, after which the piston rod with one piston attached can be shoved out of the cylinder by pushing on the end of the piston rod with a screw driver. The remaining piston in the cylinder can easily be pushed out from the other end. It is not advisable to push the piston past the opening in the center of the cylinder as the leather may be injured.

CONTROL MAGNET VALVES

Electro-pneumatically operated devices are provided with magnet valves which govern the admission of air to and the exhaustion of air from the air-operated cylinders. Magnet valves fall naturally into two general classifications as to operating principle: namely Standard and Inverted Valves.

The Standard Valve when energized, admits air from the pressure line through a small port or seat allowing the air to pass

through the valve and into the air cylinder which actuates the complete piece of apparatus. In this valve the full pressure of the air line or reservoir acts continuously in the cylinder, as long as the magnet coil is energized; while another valve on another seat prevents the air from escaping through the magnet valve exhaust port.

In Fig. 22 is shown the diagrammatic cross-sectional view of a standard magnet valve with the operating parts in the position

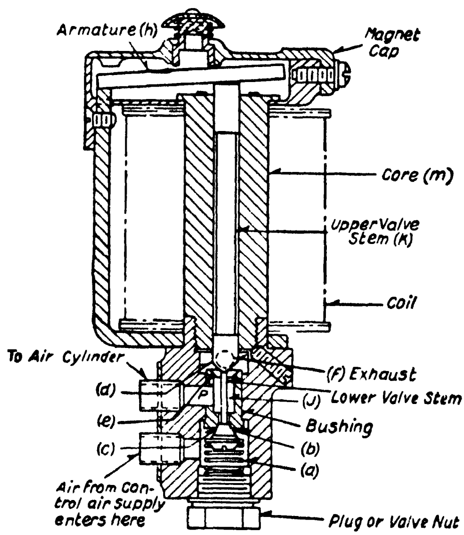


Fig 22. Cross Section of Open-Coil Type Standard Magnet Valve

which they occupy when there is no current passing through the coil. Under this condition the spring (*a*) pushes the valve (*b*) up against the seat (*c*) and prevents any air from passing from the control air supply to the operating cylinder. The spring (*a*) not only closes the valve (*b*) but at the same time lifts the valve (*d*) off its seat (*e*) and leaves a clear opening for the escape of air from the operating cylinder through the passage (*j*) and (*f*) to atmosphere. When the magnet coil is energized the armature (*h*) pushes down on the stem (*k*), opens the valve (*b*) and admits air from the supply to the operating cylinder through the passage (*p*), and at the same time closes the exhaust valve (*d*).

Several mechanical adaptations of magnet valves have been made throughout the many years during which air-operated control systems have been used.

Inlet Valve Leakage. Occasionally a valve will blow (i.e. give out a hissing sound) due to leakage of air; if this occurs when the magnet coil is de-energized and the air blows out of the magnet exhaust port (*f*), Fig. 22, it is an indication that the lower (inlet) valve is not seating properly. This trouble is caused generally by the presence of a little dirt on the valve seat and in most cases can be cured by pressing down the pin in the top of the magnet valve and releasing it quickly several times. If the blowing persists, shut off the air from the apparatus and unscrew the plug at the bottom of the magnet valve. Carefully lower the plug straight down and the spring and lower valve will drop down with it. Wipe the valve perfectly clean and with a small stick and piece of cloth also clean the valve seat.

When replacing the lower valve, spring, plug or valve nut, first remove the cap over the armature so that in case the valve stem does not properly enter the hole in the stem (*k*), Fig. 22, it is free to be lifted by the advancing stem instead of being damaged. If the inlet or exhaust valve is not tight, the difficulty can sometimes be overcome by inserting a small screw driver in the top slot and spinning it a few times on the seat.

Exhaust Valve Leakage. In case a standard valve blows through the exhaust port when the coil is energized it is a sign that the exhaust valve (*d*), Fig. 22, is not seating properly on the seat (*e*). This may be due to any one of the following causes which are mentioned in the order of their usual liability of occurrence. (Refer to Fig. 22.)

(1) Dirt on the valve seat (*e*).

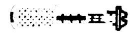
(2) Weak battery or low voltage applied to coil.

(3) Dirt under the magnet armature (*h*).

(4) Valve stem (*k*) worn down so that armature strikes the core (*m*) before the valve seats.

To remove the stem (*k*) it is not necessary to shut off the air. First remove the cap over the armature and lift out the armature which is not fastened in any way. Next, place a finger of one hand

Style No. 757464
SCRAPER FOR STANDARD UPPER VALVE STEM

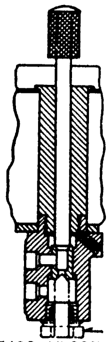


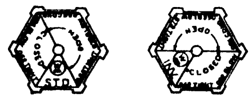
Style No. 223682
SCRAPER FOR STANDARD LOWER VALVE

To be used for reseating worn valves before regrinding. New valves do not require scraping.

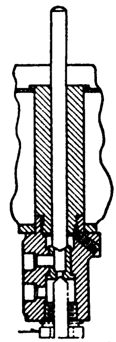
ADDITIONAL BENCH TOOLS

Whirligig or Valve Grinder	Style No. 414800
Bit for $\frac{5}{32}$" Valves	Style No. 414804
Bit for $\frac{7}{32}$" Valves	Style No. 414802
Bit for $\frac{5}{16}$" Valves	Style No. 757468
Bit for $\frac{21}{64}$" Valves	Style No. 414803
Extension Bit (".308 Dia.) for Floating Valves	Style No. 757472
Core Wrench for ".325 Core Stems	Style No. 757466
Core Wrench for ".218 Core Stems	Style No. 1086871





Style No. 754434
VALVE SETTING GAUGE
Fig. 1



GUIDE NUT
Style No. 757465

Style No. 757462 (".325 dia. shank)
SCRAPER FOR VALVE BUSHING

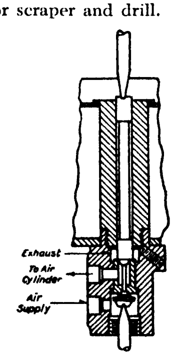
Style No. 757463 (".325 dia. shank)
SET FOR VALVE BUSHING

To be used before grinding in new valve bushings and also for reseating worn valve bushings before regrinding.

New bushings are supplied with small drilled hole for ports, which must be drilled out to same size as old bushings after new bushing is in place.

Drill clearance hole for scraper in a lower valve nut as shown and use this as a guide for scraper and drill.

Fig. 2

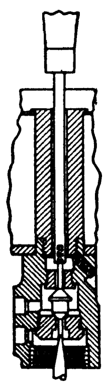


METHOD OF GRINDING
STANDARD VALVE

Cover the surface of valve seat with a mixture of powdered pumice stone and oil, and spin the valve on the bushing with a screwdriver until seat is tight.

The pumice should be removed before testing for a leaking valve.

Fig. 3

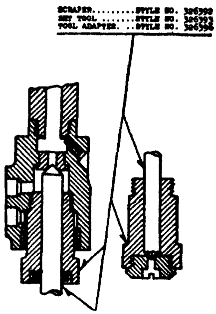


METHOD OF GRINDING
INVERTED VALVE

Spin valve with tool Style No. 249746 for grinding lower seat and with screwdriver for upper seat.

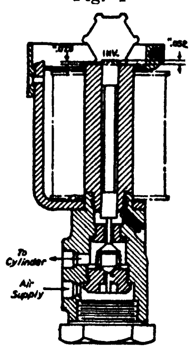
Fig. 4

Fig. 23. Tools and Instructions for Servicing Magnet Valves



METHOD OF SETTING AND SCRAPING INVERTED MAGNET VALVE BUSHINGS FOR RESEATING NEW OR WORN VALVE BUSHINGS BEFORE REGRINDING

Fig. 4



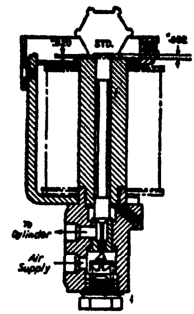
METHOD OF CHECKING AND ADJUSTING FINAL GAP AND LENGTH OF NEW PUSH ROD INVERTED VALVES

New push rods have excess length. After assembling and grinding as shown in Fig. 4, flat-file the top of the push rod until the ″.052 gauge will discharge the cylinder with a slight leak, and the ″.049 gauge discharges the cylinder with the valve tight. The final air gap is then between the two, or approximately ″.050.

The travel is set at the factory as between ″.017 and ″.027 by proper machining of the bushings and floating valve. To check this, the ″.079 gauge should not make the valve blow, but the ″.066 gauge should cause a slight leak. Both tests should be made with the cylinder charged with air.

In service, it is permissible to allow the push rod to wear until the final gap is ″.032, or ″.012 more than the brass residual stops in the core face. The ″.056 gauge will at this point fail to unseat the exhaust and the push rod must be stretched by peening or a new rod used.

Fig. 6



METHOD OF CHECKING AND ADJUSTING TRAVEL AND LENGTH OF NEW UPPER AND LOWER VALVE STEMS

STANDARD VALVES

Upper Valve Stem

New Stems, both upper and lower, have excess length. Grind both to a tight seat as shown in Figs. 1, 2 and 3. Flat-file the top of the upper stem until the ″.056 gauge will operate the cylinder with a slight leak and the ″.052 will close the valve tight. The final air gap is then between the two, or approximately ″.054.

In service, it is permissible to allow the upper stem and seat to wear until the final gap is approximately ″.032, or ″.012 more than the bronze residual stops in the core face. The ″.066 will at this point fail to unseat the lower valve and the upper stem must be stretched by peening or a new stem used.

Lower Valve Stem

After the upper stem has been adjusted as per instructions just given, try the valve with the ″.088 gauge. This will probably cause the valve to unseat and blow due to excess length of the lower stem. The lower stem should be flat-filed until the ″.088 gauge will not touch but the ″.079 will unseat the lower stem. The total gap is then approximately ″.086 and the travel is ″.086 minus ″.054, or ″.032.

In service, it is permissible to allow the push rod to wear until the final gap is ″.032, or ″.012 more than the bronze residual stops in the core face. The ″.056 gauge will at this point fail to unseat the exhaust port and the push rod must be stretched by peening or a new rod used.

Fig. 5

Fig. 23. Tools and Instructions for Servicing Magnet Valves—*Continued*

over the magnet valve exhaust port (*f*) and press down on top of the valve stem with a finger of the other hand and then raise the finger quickly. The valve stem will be raised by the air pressure and can be readily lifted out and the end of the valve wiped clean.

A weak battery will sometimes give a sufficient pull to unseat the lower valve but not enough to close the exhaust. The obvious remedy is to charge the battery.

Another possible cause of a blowing exhaust valve, i.e. worn down stem (*k*), Fig. 22, is very unlikely to occur until after the equipment has been in service for several years. If this stem is found to be too short it can be slightly stretched by peening the shank.

MAGNET VALVE INSPECTION AND MAINTENANCE.

Valve Grinding. In order to obtain satisfactory operation from the electro-pneumatic valves, it is necessary to maintain the travel of the valve and the final gap between the magnet armature and the core, within certain limits.

After a considerable period of service the valves wear down and it is necessary to refit or replace them. In order to accurately determine their condition a simple gauge, Style No. 754434, is employed. This gauge is used for both standard and inverted valves by turning it over, depending on the type of valve to be checked.

Standard Valves. Gauge S No. 754434 is used to check and adjust the final gap and the length of new upper valve stems. See Fig. 1 of Fig. 23. Remove the magnet cap and insert the gauge as shown. Flat file the top of the upper stem until the .056 inch gauge will admit air to the cylinder with a slight leak out the exhaust and the .052 inch gauge will close the exhaust valve tight. The final air gap is then between the two, or approximately .054 inch. New stems have excess length and should be ground to a tight seat before adjusting the gap. Directions for grinding are included in a later paragraph.

In service, it is permissible to allow the upper stem and seat to wear until the final gap is approximately .032 inch. The .066 inch gauge will at this point fail to unseat the lower valve to admit air to the cylinder and the upper stem must be stretched by peening or a new stem used.

The same gauge S No. 754434 is used, after the upper valve stem has been adjusted, to adjust the travel and the length of the lower valve stem. Use the .088 inch gauge. This will probably cause the valve to unseat and blow due to excess length of the lower stem. The upper end of lower stem should then be flat-filed until the .088 inch gauge will not touch but the .079 inch gauge will unseat the lower stem. The total gap is then approximately .086 inch and the travel is .086 inch minus .054 inch or .032 inch. In service, it is permissible to allow the lower stem to wear as long as the condemning gauge .066 inch makes the lower valve blow when the upper stem is new. If it does not, the travel has then reached .012 inch and the lower stem must also be stretched by peening or a new stem used.

Grinding Valves. It is occasionally necessary to grind in leaky valves. Use prepared grinding compound for this purpose, or make a thin paste of very finely ground pumic and machine oil. Apply a little grinding compound on the valve seat, put the valve in place and spin it back and forth with a screw driver.

When grinding the lower valve, the upper stem or pushrod should be in place to act as a guide. After grinding, the stems and valve seats should be thoroughly cleaned, by using a little gasoline and blowing out with air.

For detailed instructions and convenient tools for use in grinding or servicing valves see Fig. 23.

CONTROL MAGNET VALVE TOOLS
(Co-ordinate Type Valves)

The following list of control magnet valve tools covers those generally needed to facilitate work on the apparatus. See Fig. 23 on "Tools and Instructions for Servicing Magnet Valves."

Tool	Style No.
Standard Valve Seat Scraper (.325 inch dia. shank)	757462
Inverted Valve Seat Scraper (.434 inch dia. shank)	326392
Standard Valve Seat Set (.325 inch dia. shank)	757463
Inverted Valve Seat Set (.434 inch dia. shank)	326393
Standard Upper Valve Stem Scraper (.315 inch dia. stem)	757464
Standard Lower Valve Stem Scraper	223682
Guide Nut for Standard Valve (.328 inch hole)	757465
Tool Adapter for Grinding Lower Bushing in Inverted Valve (.434 inch hole)	326396

Tool	Style No.
Core Spanner Wrench (.313 inch Center Pin, 29/32″ Spanner)	757466
Core Spanner Wrench (.206 inch Center Pin, 29/32″ Spanner)	1086871
Whirligig Valve Grinder	414800
Steel Bit for Whirligig Grinder, 5/32″	414804
Steel Bit for Whirligig Grinder, 7/32″	414802
Steel Bit for Whirligig Grinder, 5/16″	757468
Steel Bit for Whirligig Grinder, 25/64″	414803
Extension Bit for Whirligig Grinder for Grinding Floating Valve with ⅛″ stem (.308 inch dia., 3½″ long)	757472
Valve Grinder with Handle Grip for Grinding Floating Valve with .127 inch stem (4″ shank, .210 inch dia.)	249746
Magnet Valve Gauge	754434
Socket Wrench (.242 inch hex. nut)	466807
Socket Wrench (21/64″ Sq. hd. bolt)	1016513
Socket Wrench (25/64″ Sq. hd. bolt)	1016795

Screw driver, socket wrenches, and other standard tools as required.

ELECTRO-MAGNETIC CONTACTORS

(1) **Auxiliary Contactors (When Used).** Auxiliary contactors are small magnetically operated switches, used for the purpose of closing and opening auxiliary circuits; they are operated by low voltage from the battery circuit.

Each contactor comprises a stationary and movable contact, an electro-magnet for bringing the contacts together, a "blowout coil to extinguish the arc, and arc shields to protect the metal portions of the switch."

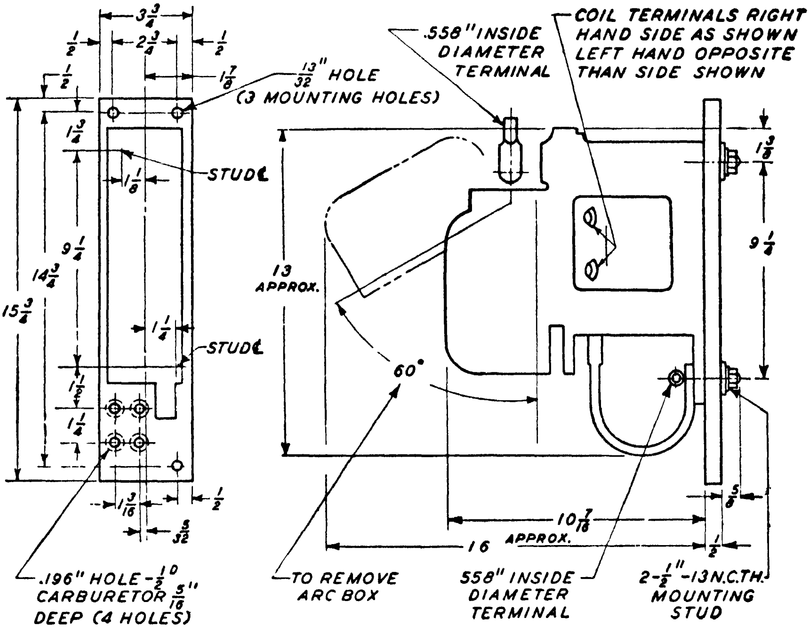
The stationary and moving contacts are made of hard drawn copper of sufficient section to give long life. Burning at opening and closing occurs only at the tips of the contacts and does not affect the current-carrying surfaces; a slight whipping action when closing insures a clean, low-resistance contact area. A steel compression spring insures positive contact pressure, regardless of wear, and also causes quick-opening of the contacts.

The arc shields are made of molded heat resisting material and are hinged so that they may be easily rotated by hand for inspection of contacts.

(2) **Maintenance of Auxiliary Contactors.** No oil or other lubricant should be used on the copper contacts. The contacts normally wear to give the best contact surface without any attention; roughened appearance is no indication that good contact

is not being obtained. Clean the contact surfaces with fine sandpaper when the wear on the faces causes excessive roughness.

(a) *The copper contacts* should be renewed when the tips are burned away to the extent that the current-carrying surfaces are materially affected. Contacts may be removed by taking out a single



TYPE	LOCATION OF COIL TERM. RIGHT HAND OR LEFT HAND SIDE
UMA—225-A	LEFT HAND
UMA-275-A	RIGHT HAND
UMA—325-A	LEFT HAND
UMA—375-A	LEFT HAND

Fig. 24. Engine Starting and Motor Field Shunting Contactors

screw; neglect of contact renewal may allow the arc to burn the contact screw, making it difficult to remove, or may otherwise damage the contactor.

Contacts sometimes wear quickly as the result of too small a travel and very little wiping action. This may be caused by a bent hinge pin, insufficient free movement of the armature, or too strong a finger spring.

(b) *The bearings* of the hinge pin and armature shaft require no lubrication; oil quickly collects dust and, unless parts are frequently cleaned, will interfere with the operation.

The bearings and hinge pin should be kept in perfect condition; decreased contact pressure may result from a worn hinge pin or a weak finger spring; in either case the defective part should be renewed promptly.

(c) *Arc shields* should be renewed before the molded material is burned away sufficiently to expose the metal poles, the shield may be removed easily by taking out a single bolt.

(d) *The flexible copper shunt* should always be held tight by the studs and rivets; if the rivets become loose, there is danger of the shunt burning through at that point.

(e) *The operating coil* may be removed readily by lowering the armature, disconnecting the terminal loads, and removing a single screw. Coils are designed to operate the contactor successfully at from 80 per cent to 110 per cent of normal voltage, and to stand 110 per cent voltage continuously without overheating; coils are impregnated in order to make them resistant to moisture and oil.

(f) *The sealing surfaces* of the magnet core and armature should be kept clean.

(g) *The interlocks* should be properly adjusted so as to make contact at the correct point; care should be exercised that both *in* and *out* interlocks on the same contactor do not make contact at the same time.

(h) After the locomotive has been run, an inspection can be made immediately upon shutdown of contactor condition by feeling the temperatures of the contacts and interlocks by hand. The warmer ones should be adjusted. This same method of inspection can be applied to other contacts.

(i) *The pull-in voltage* of the contactor should be determined at overhaul and the contactor set to pull-in at 80 per cent of normal voltage.

(j) *Faulty or erratic operation* may occur due to too high a pull-in voltage or binding at bearing or other points.

STORAGE BATTERIES, MAINTENANCE AND OPERATION

It is important to adjust the voltage regulator to maintain a fully charged battery and at the same time not to over charge it. Since the correct voltage regulator setting to use depends on the working schedule of the locomotive and control adjustment, the following table may be used for the initial adjustment. (Locomotives using a 56-cell battery are normally delivered with the voltage regulator set at 125 volts.)

OPERATING SCHEDULE
TOTAL TIME ENGINE RUNNING

	12-16 hrs.	16-20 hrs.	20-40 hrs.
Voltage Regulator Setting (Volts Per Cell)	2.32–2.30	2.30–2.27	2.27–2.25
Example:			
56 Cell Battery	130–129	129–127	127–124.5

Correct charging will keep the battery in a well charged condition daily and provide maximum battery life. The following instructions explain how to determine when the battery is being charged properly and adjustments to make for any necessary corrections.

The battery normally requires not over ⅜ inch of water addition per cell each month. If more water is required and the battery maintains full charged gravity, it indicates that the battery is receiving too much charge and the voltage regulator should be lowered ½ to 1 volt. When the battery temperature is 15°F. above the surrounding temperatures and the gravity is maintained at maximum, it is a definite indication that the regulator voltage may be reduced.

If the battery operates with the specific gravity below that indicated in the following table, then the voltage regulator should be increased.

TABLE FOR A 1.280 FULLY CHARGED SPECIFIC GRAVITY BATTERY

(Maximum) Fully Charged Reading When New	Specific Gravity Range to be Maintained
77°F.–1.275 to 1.285	Maximum to minus 30 points
32°F.–1.290 to 1.300	Maximum to minus 10 points
0°F.–1.300 to 1.310	Maximum to minus 10 points

Note: The Density of the battery electrolyte increases as the temperature decreases.

The engine running time period referred to in the table is considered that time during which the speed of the auxiliary generator is sufficient to maintain the required voltage to have it connected to the battery circuit. The voltage for an auxiliary generator required to maintain a battery charged will vary depending upon the number of hours a day that the auxiliary generator is operating at a speed sufficient to maintain a voltage equal to or above the battery voltage, and the main generator is supplying the energy to the connected load. Because of the effect of temperatures below 40°F., use a regulator setting for the auxiliary generator 10 volts higher than that used for normal temperature conditions.

The specific gravity of the battery electrolyte may be used as a guide to keep the battery in a fully charged condition. The following table indicates the maximum specific gravity ranges at several temperatures.

TABLE OF FREEZING POINTS OF BATTERY

Specific Gravity	Freezing Point
1100	19°F.
1125	13°F.
1150	5°F.
1175	—4°F.
1200	—16°F.
1225	—35°F.
1250	—62°F.
1275	—85°F.

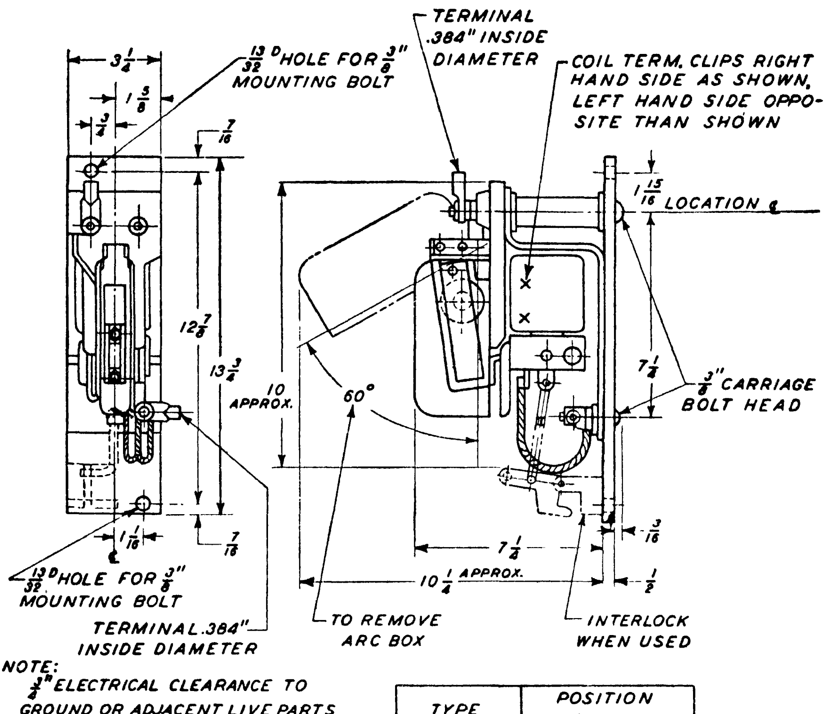
The term *maximum specific gravity* refers to the fully charged specific gravity. This maximum value may decrease with age, the amount of decrease varying and depending upon the care taken when adding water to the cells. Overflushing when adding water causes a reduction in fully charged specific gravity (a battery will remain dry on top when water additions are properly made).

Water Additions. Water that has been approved for battery service should be added at least once a month, or before level lowers to splash cover. Do not add higher than ⅛ inch below bottom of filling tube.

Cleanliness. Vent plugs should always be replaced securely after each water addition. Keep written record of water additions.

Keep the battery dry and clean. Have vent plugs in place at all times. Check tightness of the bolted connections.

Readings and Records. Following the customary practice of taking daily hydrometer readings is recommended. This provides



TYPE	POSITION OF TERM CLIPS	
	R.H.	L.H
UMJ-34-A		2
UMJ-134-A		2
UMJ-234-A		2
UMJ-334-A		2

Fig. 25. Field Control Contactors

a means of detecting faulty charging conditions and maintaining continuity of service. Care should be exercised not to spill or lose acid when taking readings. Check voltage regulator periodically.

Annual Inspection. At least once each year, or after reported battery trouble, carry out the following instructions:

(A) Add water ⅛ inch below bottom of filling tube.

(B) Charge battery at finishing rate and continue charge until the specific gravity of the lowest reading coil will rise no higher when the reading is taken once every two hours.

(C) When charge is complete, but before taking off charge, read and record the voltage of each cell. Then stop the charge. Five minutes later record the specific gravity and temperature of each cell.

(D) Battery should be removed from service and shopped if:

(1) The specific gravity of any cell reads 40 points lower than the highest.

(2) The average specific gravity of all cells is 15 points below normal.

(3) The voltage of any cell is 0.10 volt below the average. The temperature of any cell is 10° F. above the average.

Yard Charging. Yard charging should not be necessary if the charging equipment is kept properly adjusted. Should an emergency make yard charging necessary, use a rate approximately three times the finishing rate and stop charge when cells start to gas.

MISCELLANEOUS CONTROL DETAILS

Master Controller Description. The master controller contains a single lever which is used for selecting the direction of locomotive movement as well as selecting the motor connections.

The lever operates an insulated drum on which are mounted small copper segments. Stationary fingers mounted on insulated supports on the controller base make contact with the drum coils of the switches and control devices.

The controller is provided with a magnetic lock which prevents movement of the lever from *off* to the operating positions or return unless the coil is de-energized. The coil is energized by the manual engine throttle lever switch when the throttle is in the running position.

The controller should be examined at regular inspection periods to make sure that the connections are tight and that the fingers are making good contact. The fingers should give approximately 1½ to 3 pounds pressure on the drum segments. Since the fingers are of

the compensated type with fixed springs to control the pressure, no adjustment is needed.

The drum segments should be kept clean and occasionally a few drops of oil should be spread over their surfaces and wiped off with a clean cloth. Do not use more oil than is necessary to keep the segments from cutting.

The bearings and other working surfaces should be lubricated occasionally with a few drops of light machine oil.

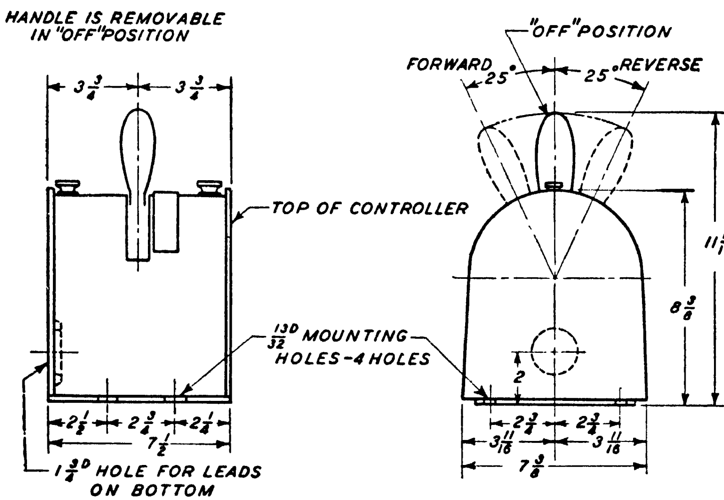


Fig. 26. Controller Outline

The magnetic lock should be examined periodically to insure that all bearing surfaces are free from binding. The bearings should not be oiled. Check the coil for tight connections.

Close the armature by hand and set air gap between the stop and armature to $3/16$ inch. Bend stop if necessary. Adjust spring so that armature seals on 70% normal voltage on the coil.

Field Shunt Relays. These relay panels consist of either two relays and two resistor tubes on an insulating base or one relay and a resistor tube on a base. The relays are exactly alike in mechanical details and coils, but they may be adjusted to operate at difficult voltages. The correct operating voltages are indicated on the wiring diagram, Fig. 37. Each coil is connected in series with one of the resistor tubes.

The relay is a clapper type device mounted on hardened pivot bearings which are covered by a felt washer to exclude dust and dirt.

The pivot points are used to minimize friction and a counterweight is attached to the armature to balance the moving parts and minimize the effect of vibration. The moving and stationary contacts have contacts with silver tips.

These relays are adjusted to two voltages. One is the so-called pickup voltage which is the voltage at which the coil overcomes the pull of the spring and pulls in the armature. The other voltage is the dropout which is the voltage at which the tension of the spring overcomes the pull of the coil and pulls the armature back away from the coil.

Three adjustments are required to calibrate these relays. One is the tension of the spring, the second is the air gap when the relay is closed, the third is the air gap when the relay is open or de-energized. These adjustments have been made at the factory and should not need to be changed. These adjustments have all been soldered so that the vibration on the locomotive will not change them.

The effect on the pickup and dropout voltages of the three adjustments are as follows:

(a) Increasing the tension of the spring raises both the pickup and dropout voltages. Decreasing the tension lowers both the pickup and dropout voltages.

(b) With the relay de-energized, increasing the air gap (by means of the stop screw) raises the pickup voltage and does not affect the dropout. Decreasing this air gap lowers the pickup voltage without affecting the dropout.

(c) With the relay picked up, decreasing the air gap (by means of the residual screw) lowers the dropout voltage without affecting the pickup. Increasing this air gap raises the dropout voltage without affecting pickup.

Another adjustment (which may or may not be used) is the jumper on the resistor tube, but this adjustment is determined at the factory and must not be changed. If a new resistor tube is installed, care should be taken that it be assembled with the identification band at the lower end of the relay panel and the position of the

jumper on the old tube should be noted. After replacing with a new tube the jumper should be installed on the tap corresponding to the tap on the old tube.

If possible the relay panel should be removed to a bench with a source of variable voltage with a range covering the pickup and

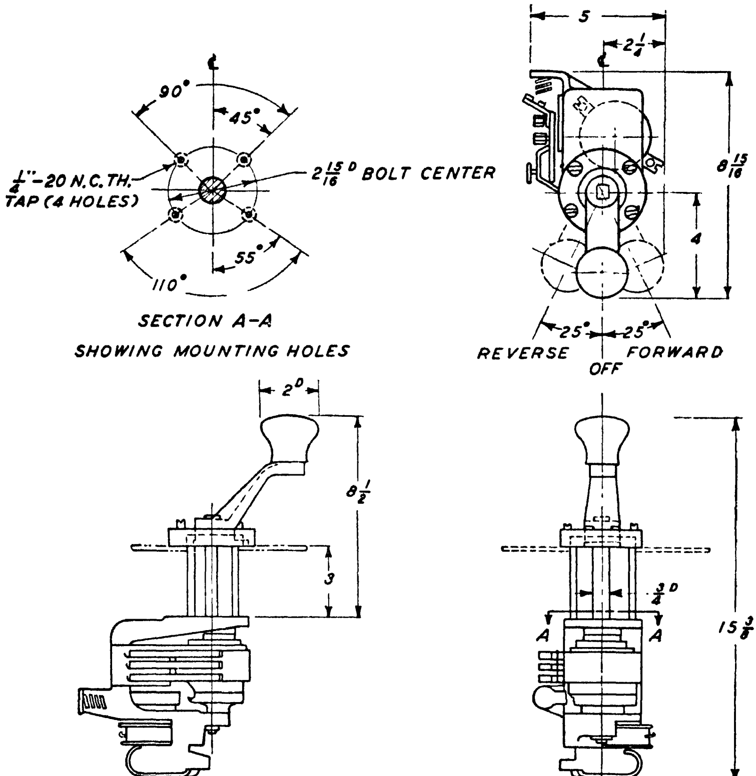


Fig. 27. Transportation Control Type 7C-285-C Controller Outline

dropout voltages. It is possible to adjust these relays on the locomotive if the circuit to the traction motors is broken, or it may be possible to adjust them while the locomotive is in operation.

Maintain the pickup and dropout voltages shown on the wiring diagram, Fig. 37, by changing the proper adjustment. This will only be required at infrequent intervals provided the adjustments are re-soldered to prevent locomotive vibration from affecting them. The fingers should be kept in adjustment as they wear. The fingers

should deflect $1/16$ inch when in contact with their studs. The air gap between finger and contact stud should not be less than $3/32$ inch and the relay should not float either in or out.

Miscellaneous Switches and Fuses. All hand switches and fuses should be inspected regularly to cover the following:

(1) Switch jaws, fuses and fuse clips making good contact.

(2) Leads firmly soldered, terminals and bolts tight.

(3) Panels or bases clean, free from oil and dust.

(4) Correct fuses in use, spare fuses available, and auxiliary apparatus tested if one fuse blows frequently.

(5) Any springs correctly in place and operating.

(6) Apparatus tested for proper operation.

(7) Contacts clean and smooth.

This inspection should cover all items such as control and miscellaneous switches and fuses, traction motor cutout switches.

Knife Switches. Manually operated knife switches are used in the battery and motor cutout circuits.

These switches require little attention. Switch jaws should be inspected periodically to insure good contact. All leads should be firmly soldered in the connectors, and connector bolts kept tight.

Push Button Box. Push buttons compactly housed in a small box are used for controlling various lighting and auxiliary circuits. Each circuit carries only control voltage and is fused separately within the box. To facilitate inspection of contacts and renewal of fuses, the entire interior of the box is exposed when the hinged cover forming the front of the box is opened.

Copper contact bars are carried on movable insulating blocks and each bar makes contact with a pair of stationary compensated type fingers. The contact pressure should be between 1½ and 3 pounds per finger. For inspection and maintenance instructions see following section on interlocks.

VOLTAGE REGULATOR. The voltage regulator is of the vibrating type. It consists of a voltage relay element which varies the auxiliary generator shunt field current to hold constant voltage on the auxiliary circuits regardless of engine speed and auxiliary load and a current-limiting relay element which prevents overloading the auxiliary generator.

Description of Voltage Element. The relay consists of a powerful magnetic circuit which is excited by a stationary and a moving coil. The moving element is mounted upon knife edges and operates against a spring in tension. The relay is energized when the correct operating current flows through its coils and the moving contacts are actuated in the direction opposite to the pull of the spring.

Reference to the schematic wiring diagram, Fig. 37, will indicate the connections of the resistors used in conjunction with the regulator. When the engine is not running, the regulator spring holds the moving contacts against the right-hand stationary contacts. This causes the resistor in series with the generator field to be paralleled by the resistors in series with the right-hand contacts.

If the engine is started and brought up to idling speed, the voltage of the generator increases to the value for which the regulator is adjusted. When this occurs the magnetic pull of the regulator coils overcomes the spring tension and the moving contact swings away from the right-hand contacts. This breaks the current flowing through their resistors and lowers the generator field current, thus lowering the generator voltage slightly. The magnetic pull of the regulator coils is weakened and the spring again closes the contacts. This vibrating action is rapid enough so that no flicker will occur in the lights. In order to maintain rapid vibration, a small resistor tube mounted on end on the regulator panel is so connected that each time the right-hand contacts make circuit the voltage applied to the regulator coil is raised slightly. The magnetic pull thus overcomes the spring tension immediately so that no noticeable change in generator voltage appears. The rate of vibration is fixed by the resistor value and is not adjustable.

As the engine speed is increased the auxiliary generator voltage tends to rise. This increases the magnetic pull of the regulator coils so that the moving contacts are forced against the left-hand stationary contacts. The resistors in series with these contacts are therefore connected in parallel with the generator field and shunt some of the current out of the field circuit. This tends to lower the generator voltage, weakening the coil magnetic pull so that the spring pulls the contacts open. The moving contacts vibrate on the left-

hand contacts. When the left-hand contacts are closed the small resistor on the regulator panel shunts a little current out of the regulator coils, thus weakening the magnetic pull.

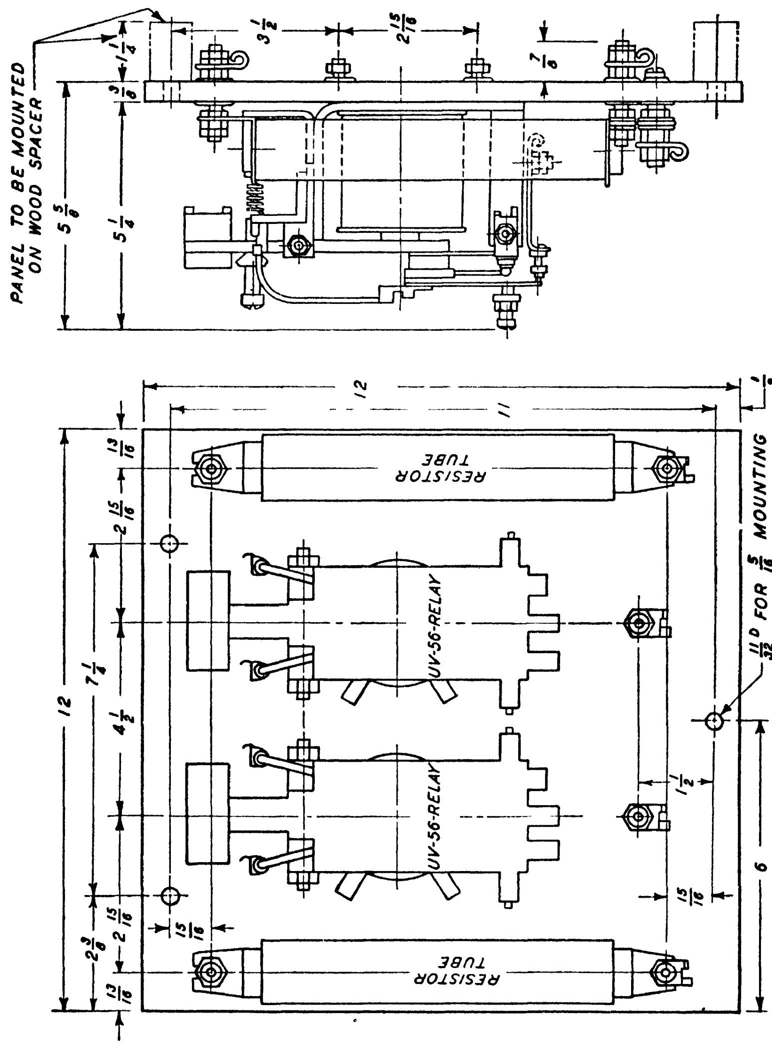


Fig. 28. Relay Panel Outline

The moving contacts therefore vibrate on one or the other sets of stationary contacts depending on the speed and load on the auxiliary generator. The intermittent operation or vibration of the

moving contacts is evidenced by light sparking at the contact surfaces, and it is audible at close proximity to the regulator.

Maintenance of Voltage Element. The sparking is fundamentally normal and will in time produce slight pitting on the graphite contact surfaces.

The normal contact gap is $\frac{3}{32}$ inch measured at the bottom of the contacts. Contacts that have worn so that the pointer on the moving coil approaches the limit lines should be adjusted. Mark the stationary contact with reference to the moving contact. Loosen the lock nut on the contact holding screw. Rotate the stationary contact the required number of *full* turns so that contact surfaces meet as before adjustment. Tighten lock nut. Explicit instructions for contact adjustment are on the plate attached to the regulator frame.

When new graphite contacts are installed, they should be carefully sanded to insure a good contact surface over the entire face. Use a strip of 00 sandpaper between the two surfaces while pressing the contacts lightly together.

Caution. Unnecessary and excessive contact sanding will only shorten the useful life of the contact and require more frequent renewal.

The moving contact should be replaced when the worn surface reaches the edge of the groove at the center of the contact. The stationary contact should be replaced when the worn surface is within $\frac{1}{32}''$ of the brass cylinder in the contact. The silver contact faces should be trued up when badly pitted. This will be required infrequently.

If it should be necessary to replace one of the regulator coils, the regulator panel should be removed from the main panel and the work done on a work bench where the renewal of parts can be facilitated under adequate and suitable conditions.

When dismantling the moving coil from the relay, care should be exercised not to damage the knife edges upon which the moving coil rocks in the **V**-blocks mounted on the main relay frame.

Any damage to the knife-edge will produce friction which will retard the motion of the moving coil and may seriously interfere with the sensitivity and proper operation of the regulator.

Damaged knife edges should be replaced with new ones rather than an attempt made to repair old ones.

Before reassembling the moving coil in the frame, the knife edges and **V**-blocks should be cleaned thoroughly to eliminate any dirt which may have collected.

After installing a new coil, its polarity should be checked by applying approximately 10 volts across the two coils connected in series. If the polarity is correct, the moving coil will pull toward the stationary coil, causing the moving contact to move to the left.

Caution. This test should not be made unless all external connections to this relay have been disconnected.

If the moving coil moves in the wrong direction, the two flexible leads of the stationary coil should be reversed and the test repeated to check.

To set the regulator on the bench, pass 2 amperes through the moving and stationary coils in series. Adjust the spring as close as possible, to the point where the moving contact floats, by means of the screw at the right-hand end of the spring. This spring *must not* be used to change the regulated voltage.

Voltage Adjustment. The regulator coils are connected in series with two non-adjustable resistor units and a small rheostat. This rheostat was adjusted to give the proper regulated voltage on the auxiliary generator and adjustment should not be changed by unauthorized persons.

Caution. Always check the regulated voltage of the auxiliary generator after making changes in regulators, and adjust the voltage by means of a rheostat and not by a spring tension.

Condensers. The regulator must not be operated without having a condenser across its contacts. These condensers are located on the back of the regulator panel.

Under proper operating conditions, there should be no heavy flashing or arcing at the contacts. If arcing is excessive, there is an open circuit probably in the condensers or the wires leading to them. If no change of field current occurs when the contacts open, the condenser is probably short-circuited.

Current-Limiting Element. In order to allow the auxiliary generator to deliver full current output and yet not be overloaded

by excessive load demands, a current-limiting relay element is provided as a part of the voltage regulator. This consists of a cast frame with regulating element. The stationary coil partially is strap-wound and carries the output current of the auxiliary gen-

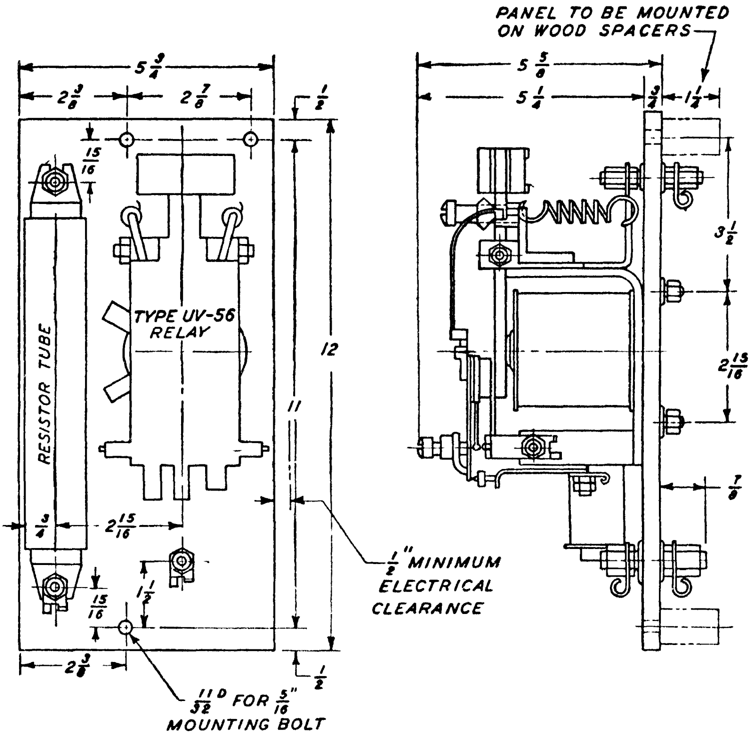


Fig. 29. Relay Panel Outline

erator. The moving coil is connected in series with the voltage element coils and a part of the current limiting element stationary coil. Thus the moving coil and a part of the stationary coil always carries two amperes only. The strap-wound part of the stationary coil is in series with the auxiliary generator armature. The pull on the moving coil is therefore a function of the auxiliary generator current.

The current element has no contacts. However, its moving coil arm carries a spring and rod arrangement with which it may exert

pressure on the moving coil arm of the voltage element. Normally the current moving coil is held *out* against a stop by its calibrating spring. When the output current exceeds the value for which the element is calibrated, the pull of the coils overcomes the pull of the spring and the moving coil moves over until the rod presses on the voltage element contact arm. Thereafter, a slight increase in current produces a sharp decrease in auxiliary generator voltage. Since this generator operates in parallel with a battery, a reduction in generator voltage reduces the current which must be delivered by the generator. In effect, therefore, the maximum output current which can be delivered is governed by the spring tension of the current element.

Maintenance of Current-Limiting Element. General maintenance instructions are the same as those for the voltage element. There should be a gap of ⅛ inch between the rod on the current element and the voltage element moving coil arm when the current element is *out* against its stop and the regulator moving contact is against the right-hand stationary contact. This adjustment is made by means of the nuts on the rod. Move both nuts the same number of turns in the same direction to maintain spring tension.

The current element can best be calibrated with the regulator installed and wired. Load the auxiliary generator up until it delivers its rated current through the strap-wound coil with the regulator in operation. Adjust the current element calibrating spring until the current moving coil rod just touches the voltage moving coil arm.

INTERLOCKS. An interlock is an auxiliary switch, mounted on a main circuit electro-pneumatic switch or electro-magnetic contactor, which establishes or disconnects a control circuit at the time of operation of its particular switch. There are two general classes the *in* interlock, which completes a control circuit when the main contacts of the switch are closed; and the *out* interlock which establishes a control circuit when the main contacts are opened. A single main switch or contactor can be equipped with *in* interlocks, *out* interlocks or a combination of both depending on the sequence required.

There are three general types, the *Butt Type* commonly used on magnetic contactors and the *Sliding Type* and *Cam Type* usu-

ally used on pneumatic switches. With the butt type a small metal arm is attached to the armature of the switch. The arm actuates a pivoted insulated block on which are mounted spring supported contacts. As the switch operates, the contacts bridge the control terminals and thus establish the circuit. With the sliding type, the control wires are terminated at compensated fingers mounted on

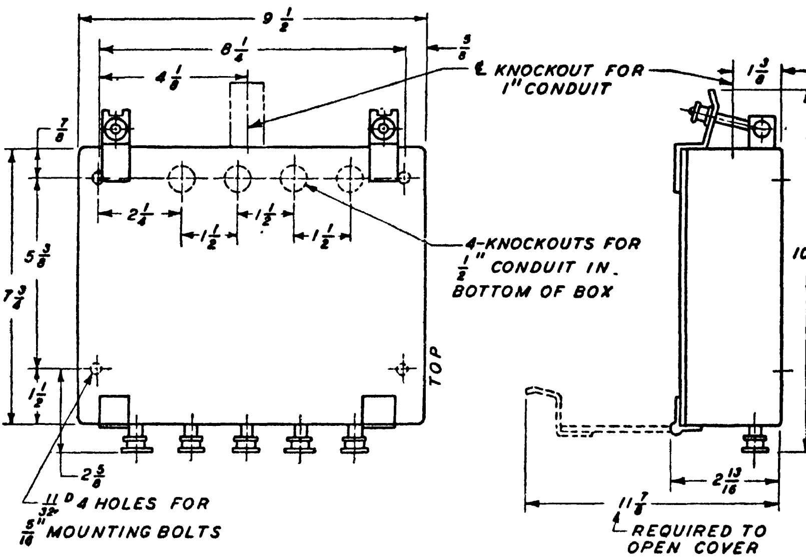


Fig. 30. Lighting Push Button Box Outline

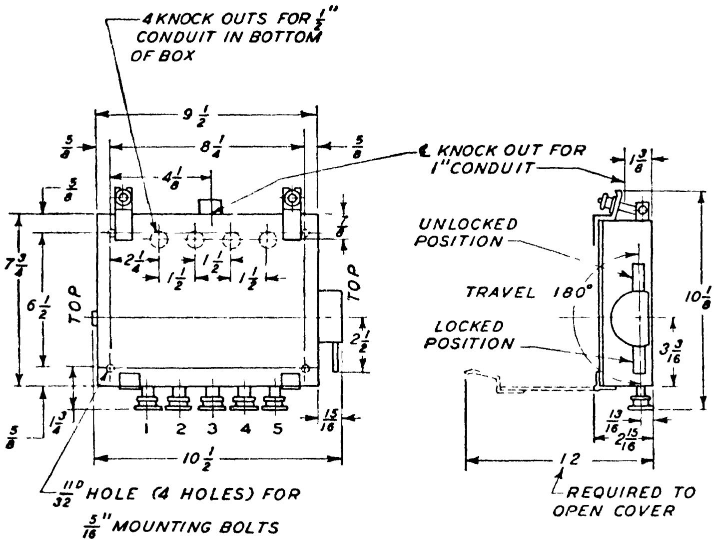
the base of the switch. An insulated block, which carries small conducting segments, is attached to the piston arm of the switch. As the switch operates the segment slides under two fingers to complete the circuit. With the cam type, the control wires are terminated at the stationary and spring fingers mounted on the base of the switch. A block attached to the piston arm carries small cams. As the switch operates, the cams close or open the spring fingers to make or break the circuit to the stationary fingers.

Interlocks have a very important function in the overall performance of the apparatus. The failure of an important interlock is sufficient to prevent operation. Trouble can be avoided by periodic inspection.

Inspection. The following examination of the interlocks should be made at inspection periods:

(1) See that the control terminals are tight.

(2) See that the interlock contacts are clean and not worn or burned.



BUTTON	NAME PLATE READING	TYPE OF BUTTON	FUSE RATING
1	BLANK	SPRING RETURN	15 AMPS.
2	FUEL PUMP	NON SPRING RETURN	15 AMPS.
3	EXCITER FIELD	NON SPRING RETURN	15 AMPS.
4	ENGINE START	SPRING RETURN	15 AMPS.
5	CONTROL	NON SPRING RETURN	15 AMPS.

Fig. 31. Control Push Button Box Outline

(3) See that there is a deflection of the spring in the interlock finger or bar when the contact is made.

(a) On the butt type this can be obtained by adjustment of the length of the interlock arm.

(b) On the sliding type this can be accomplished by putting a slight set in the finger.

(c) On the cam type this can be accomplished by adjustment of the gap between fingers. This should normally be ⅛ inch when open.

TYPE M RESISTORS. Type M resistors are used in the circuits where large resistor capacity is required. This resistor is built of tubular units having steel center supports insulated by sections of porcelain. A resistance ribbon is wound edgewise in the form of a helix about the sections of porcelain. The units are mounted on insulated tie rods supported on a strap steel frame. Each unit may be removed easily without disturbing any of the other units.

The resistors limit the amount of current flow through the respective circuits and thus have an important part in the overall performance of the equipment. Electrical characteristics of the equipment can be upset by the adjustment of a resistor in an important circuit. All resistance values are properly adjusted when the unit is first put in service. Adjustments should only be made by one who is thoroughly familiar with the performance of the complete equipment.

At light and heavy inspections the complete resistor assembly should be examined for broken porcelains and resistance ribbons. Check that all connections are tight and properly made and that the resistance ribbon is properly and securely clamped in the end terminals. The mounting insulators and frame terminal bar should be cleaned.

At general overhauls, in addition to the above inspections, the mounting bolts should be tightened and the insulating terminal bar should be cleaned, then painted with insulating varnish.

When replacing a resistor tube, care should be taken to have the terminal clamps and resistor ribbon clean, smooth and bright before making connections. It is preferable to use new terminal clamps when replacing the tubes.

CONTROL RESISTORS. The control resistors, which carry only low values of current, consist of resistance wire wound on tubes. The tubes are of various ohmic values as specified on the wiring diagram, Fig. 37.

The control resistors also have an important function in the overall operation of the electrical apparatus. The characteristics of the equipment can be disturbed by changing the values of the control resistors in important circuits. The resistors are properly adjusted when the equipment is first placed in service and should

not be tampered with. Adjustment should be made only by one who is thoroughly familiar with the performance of the complete equipment.

At light and heavy inspections the resistor panel should be examined carefully for loose connections. The resistor tubes should be taken from the panel and checked for broken or open circuited

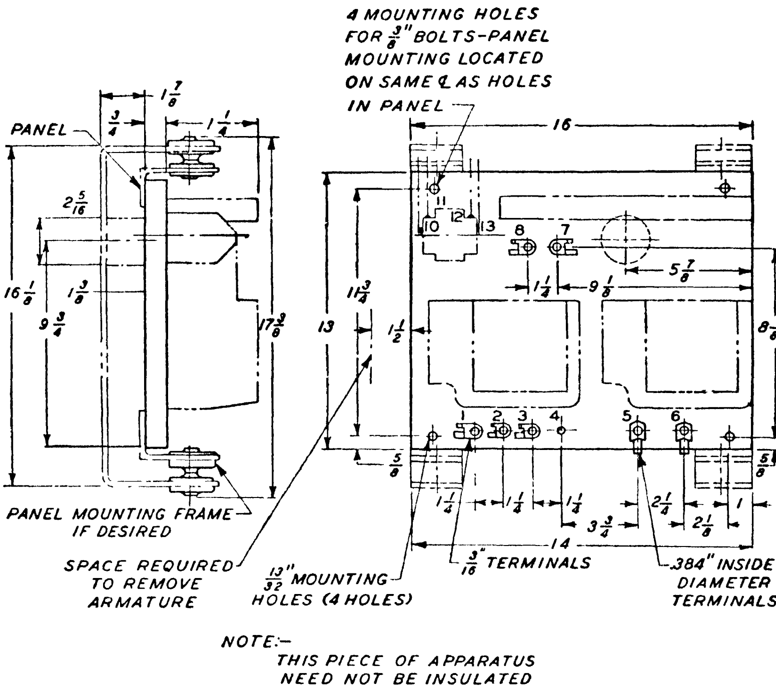


Fig. 32. Regulator Outline

tubes. Care should be exercised in replacing the tubes and making the proper connections.

Replace broken or damaged tubes only with tubes having identical style number.

THROTTLE TOGGLE SWITCH. This switch is controlled by the lever which operates the engine throttle valve in such a way that the first movement of the throttle from the *idle* position closes *run* contacts, establishing circuits to the reverse drum through which the traction motor contactors and main generator contactors

are energized. The *run* contacts remain closed until the throttle is returned to the *idle* position.

The throttle switch should be cleaned and inspected for loose terminals, poor contacts and broken springs at regular inspection periods.

The opening and closing of the switch should also be checked to insure that it pulls in before the engine speeds above idling.

The cover should be removed and the spring action checked for quickness of action.

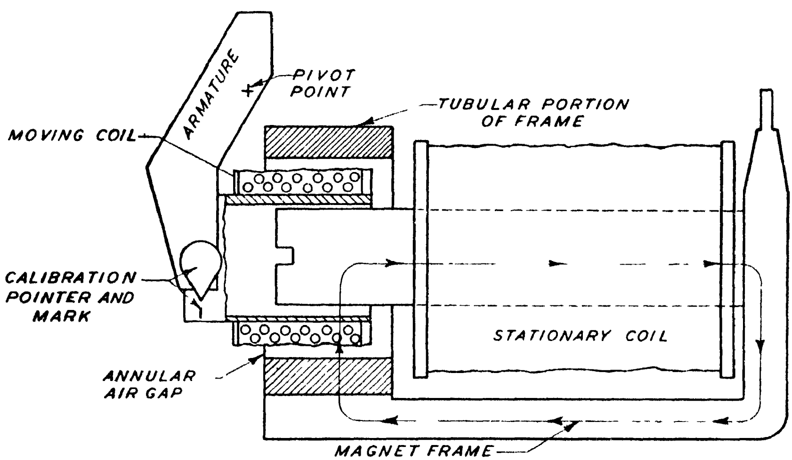


Fig. 33 Electro-Dynamic Relay

REVERSE CURRENT RELAY

Description and Operation. The reverse current relay is of the electro-dynamic type, ruggedly designed for railway service and fulfilling the requirements of extreme sensitivity and quick response.

The fundamental details of this relay are shown in Fig. 33. The relay uses a stationary coil which produces a strong magnetic field in the annular air gap. The moving coil which is fastened to the armature lies in the flux from the stationary coil. This flux follows the path shown by the arrows. The pull on the moving coil is proportional to the product of the current in the moving coil and the flux produced by the stationary coil. The air gap is sufficiently large to allow the moving coil to move within a field of uniform

strength, thus giving a pull which is independent of the coil position as long as the relay coil is adjusted to the proper operating range.

The armature is free to move about hardened tool steel pivot bearings which minimize friction and wear. On the upper end of the armature are mounted a contact, which makes when the moving coil is in as far as possible, a holding coil which prevents chattering and a contact which makes when the moving coil is out as far as possible.

The function of the relay is to close its contacts at the correct time to complete a circuit through the operating coil of the reverse current switch *A*, Fig. 34, which in turn closes the circuit connecting the auxiliary generator to the battery for charging. See wiring diagram, Fig. 34. Also when the plant is shut down it is the duty of the reverse current relay to open its contacts and open the circuit through the operating coil of the reverse current switch *A* and disconnect the auxiliary generator from the battery.

With the stationary coil energized and the current flowing in one direction in the moving coil the armature will move in one direction. If the current is reversed in the moving coil, the coil will move in the other direction. The moving coil is wound in two sections, one is a winding of a few turns of heavy wire and is connected across the relay shunt; the other is a winding of many turns of fine wire which is connected in series with a resistor across the contacts of the reverse current switch *A*, Fig. 34. The stationary coil is connected across the battery and furnishes the excitation.

When the auxiliary generator voltage is lower than the battery voltage, the difference between these two voltages is impressed on the moving coil with such polarity as to produce a force on the coil to move it out away from the stationary coil and keep the contacts in the circuit to the operating coil of switch *A*, Fig. 34, open and prevent the closing of the switch.

When the voltage of the auxiliary generator rises slightly above that of the battery, the voltage across the moving coil is in the opposite direction, the force on the operating coil of switch *A*. This closes switch *A* and connects the auxiliary generator to the battery. When switch *A* closes, it short circuits the fine wire or shunt winding on the moving coil and at the same time the main current pro-

duced by the auxiliary generator flows through the relay shunt to the battery. A portion of the main current goes through the heavy wire of series section of the moving coil, since it is connected across the shunt.

The magnetic effect of this current in the series section of the moving coil, with the pull of the holding magnet, holds the contacts closed. The coil of the holding magnet is connected in series

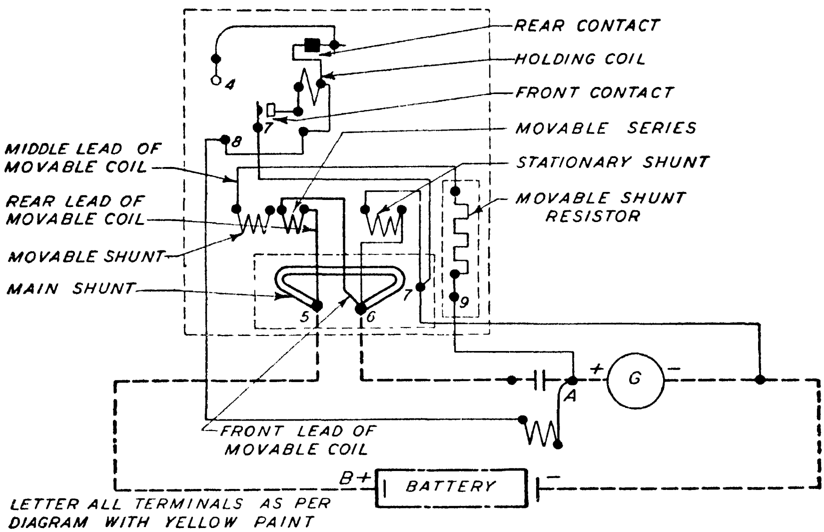


Fig. 34. Reverse Current Relay Wiring Diagram

with the operating coil of switch *A*; it only operates when the contacts are closed and attempts to keep the contacts closed.

When the auxiliary generator voltage decreases to less than the battery voltage the current in the moving coil reverses and opposes the pull of the holding magnet and produces the force necessary to open the contacts and open switch *A*. This disconnects the auxiliary generator from the battery. The above features make the relay positive in action under all conditions of operation.

Inspection and Adjustment. Tighten all bolts, nuts, and screws. If electrical connections are discolored and burned remove the terminal screws, smooth and polish the contact surfaces and reassemble.

(A) Check pivot bearing end play. This should not exceed

1/64 inch and relay armature should operate freely. Do not oil or grease pivot bearings.

(B) Set balance weight so that relay armature floats to the front contact open position.

(C) Adjust back contact until calibration pointer and mark coincide.

(D) Adjust front contact gap to 5/16 inch by adjusting front moving contact.

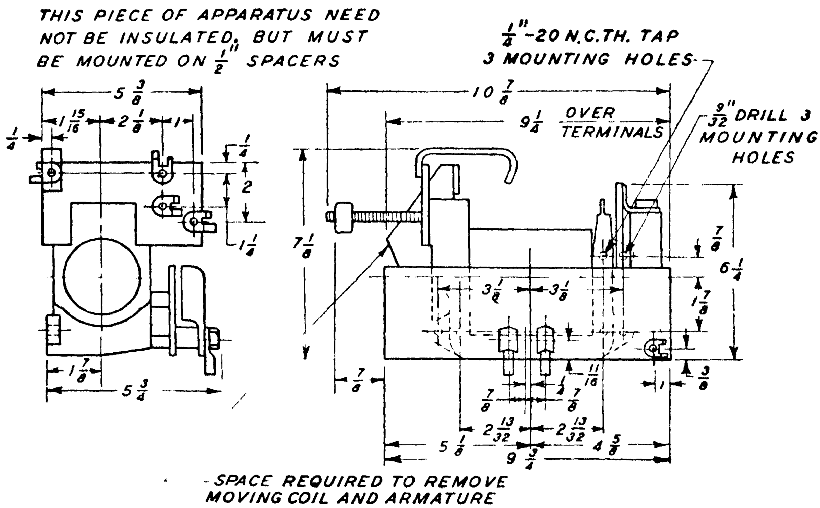


Fig. 35. Reverse Current Outline

(E) With the stationary coil across the battery, adjust the balance weight so that the relay closes its front contacts when a differential of 1 to 3 volts exists across the moving coil terminal (6 and 9). To lower the differential cut-in voltage, move the balance weight out. To raise the differential cut-in voltage, move the balance weight in.

(F) Set the armature holding coil gap so that 15 to 40 amperes reverse current from the battery through the relay main shunt will cause the relay to open its contacts while .45 to .5 amps. is passed through the holding coil. Turning the holding coil air gap screw in will lower the reverse current cutout value. To raise the cutout value, back the screw out. Tighten lock nut.

CARBONSTAT AND REGULATING VALVE

The purpose of the carbonstat is to provide automatically full load output of the Diesel engine to the generator under varying temperatures.

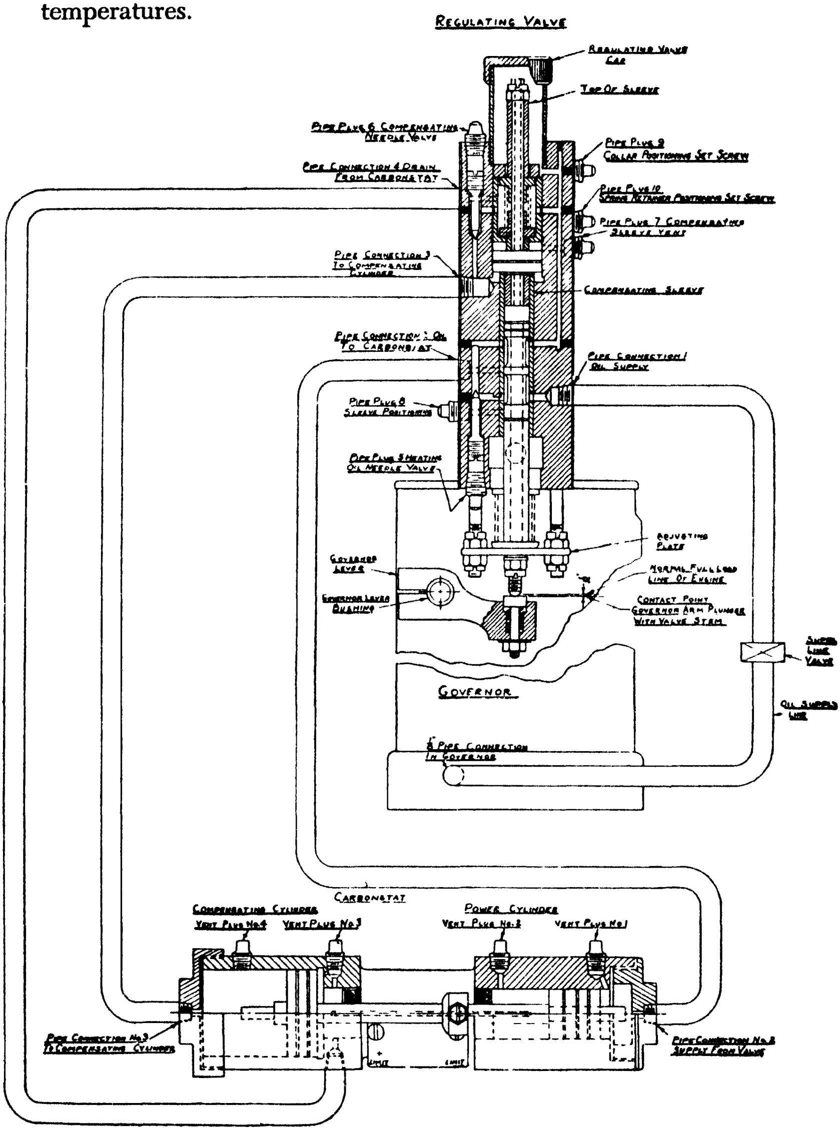


Fig. 36. Carbonstat and Regulating Valve

If correctly installed the carbonstat and regulating valve should require no attention other than periodic examinations for loose connections and leaks. If this device is suspected to be air bound or if it has been disconnected from the engine, the following instructions for reassembling are important.

1. Pipe carbonstat and valve as shown in Fig. 36.

2. Set Bosch fuel injection pumps as closely as possible to full load position. Adjust governor lever on governor lever bushing so that valve stem is lifted $1/32$ in. when pumps are in full load position.

3. Remove pipe plug No. 8 and make sure that the hole in the compensating sleeve lines up with the hole in the valve body.

4. Make sure that the governor arm plunger does not move until the valve stem is stopped by the adjusting plate. If plunger does move, adjust spring until movement is eliminated. (In this case repeat paragraph No. 2).

5. Remove regulating valve cap and pipe plug No. 5 and open heating oil needle valve very gradually making sure that oil does not run out of top regulating valve.

6. Remove pipe plug No. 6 and open compensating needle valve $1/8$ turn from seated position.

7. At the top of the regulating valve pour in oil until oil reaches top of sleeve. Next, remove vent plugs Nos. 2, 3, and 4 in carbonstat and pipe plug No. 7 in regulating valve until all air is bled off and oil runs out. During this process continually add oil sufficient to maintain the oil level at top of sleeve. Thereafter the oil level is maintained automatically by the governor.

8. Run Diesel engine at idling speed. Lifting valve stem by hand carefully loosen vent plug No. 1 in carbonstat and bleed off all air from the power cylinder. Care is advised because the oil pressure in this cylinder is at about 100 pounds.

9. Connect an ammeter in series with the carbon pile and note that current reads:

at least 4 amperès for a 6-cylinder engine
or 5-6 amperes for an 8-cylinder engine

Lift valve stem by hand and note that current drops to at least:

1 ampere for a 6-cylinder engine
2 amperes for an 8-cylinder engine

If these values are not obtained, the locomotive series resistor requires adjustment.

10. Connect a voltmeter across the carbon pile. Lift the valve stem by hand until voltmeter reaches 50 volts. Release and note the time required for the voltmeter to return to its original position. This interval should be between twenty and twenty-five seconds. If more time is required, close compensating needle valve (plug No. 6) very slightly. If less time is required, open valve slightly.

11. Having obtained the correct setting, check the time required for unloading the carbonstat by lifting the valve stem and noting the time required for the voltmeter to move to 50 volts. The time should be between five and ten seconds. If less, lower adjusting plate very gradually (¼ turn or less) and repeat this test until correct timing is obtained. Be careful not to jam the valve stem by cocking adjusting plate. If more time is required, raise adjusting plate in similar fashion.

12. Before proceeding further, be sure that the Diesel engine is in good operating condition. Be particularly sure that no exhaust smoke is present.

After the electrical setting has been made, as described above, it is necessary to synchronize the regulating valve with the engine load. This can best be accomplished by loading the engine with a water rheostat. Using this method, the engine should be run at full speed and the generator voltage plotted against generator current. The resulting curve should correspond to the performance curve shown in Fig. 2 of this chapter. If the test curve falls below the standard curve, the engine is underloaded. Additional evidence of this condition will be indicated by the fuel rack not opening to the normal full load position. To correct this, move the governor arm on the governor arm bushing in a clockwise direction. Adjust the governor arm very gradually. If the test curve is above standard, move the governor arm in a counterclockwise direction.

If a water rheostat is not available, it is possible to substitute a train in order to load the engine. If this method is used, the train load must be sufficient to register on the load ammeter:

at least 800 amperes for a 6-cylinder engine
at least 1000 amperes for an 8-cylinder engine

With sufficient load registered on the load ammeter, read the generator voltage and current at the same time. They should correspond to the performance curve shown in Fig. 2 of this chapter. Variations from the standard curve may be compensated by the same method of adjustment as described above.

When making a test by this method it is essential to use an accurate ammeter and voltmeter. An ammeter with a 100 millivolt full scale deflection can be connected to the shunt already installed in the locomotive. The voltmeter should be connected to G+ and NN on the field shunting relay.

Note: If Diesel engine *hunts,* the trouble will probably be located in the governor itself. However, *hunting* occasionally results from the presence of air in either the carbonstat or the regulating valve. Should this condition occur, bleed off air as described in paragraphs Nos. 7 and 8 of this section.

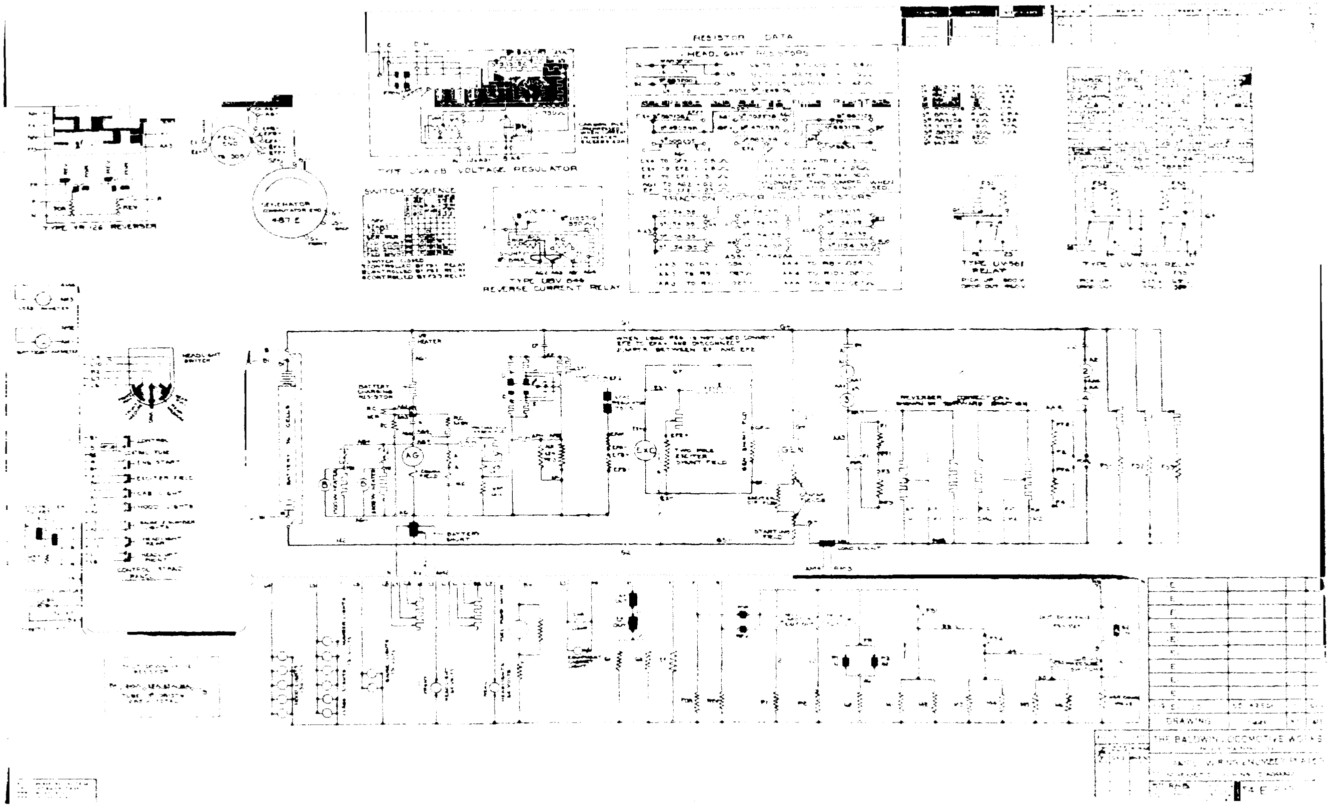
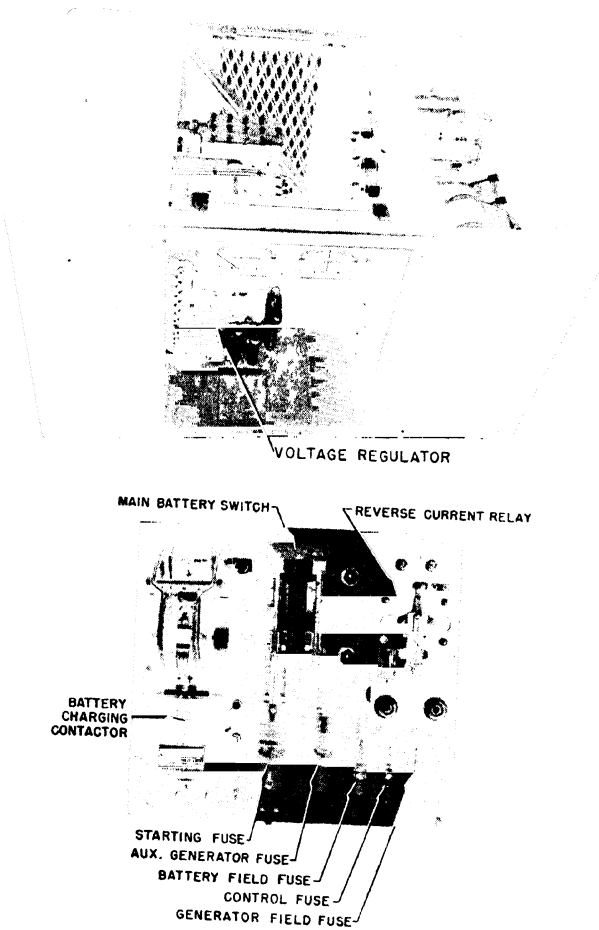


Fig. 87. Wiring Diagram



Low Voltage Panel for 1000 Horsepower Switcher Unit

Chapter VIII

Electro-Motive Equipment

This chapter covers the 600 and 1000 hp. switchers and principal features of the 2000 hp. passenger road locomotives. The 1350 hp. freight unit is not shown, but it is similar to the 2000 hp. road units in some respects. (See Figs. 1 to 30, inclusive.)

Transition (All Units Except 600 Hp.). This definition is inserted at this point so that the reader who is unfamiliar with this term will not be confused by its use in later pages.

This term applies to the changing of the traction motor electrical connections from series to parallel or to shunt. This is done to obtain the desired tractive effort and speed within the voltage operating limit of the generator.

To obtain maximum tractive effort from the motors when the train is at low speed, they are connected in series. As their speed increases, the generator voltage increases until the voltage (transition) relay closes, operating the traction motor contactors, connecting the motors in parallel. This reduces the generator voltage.

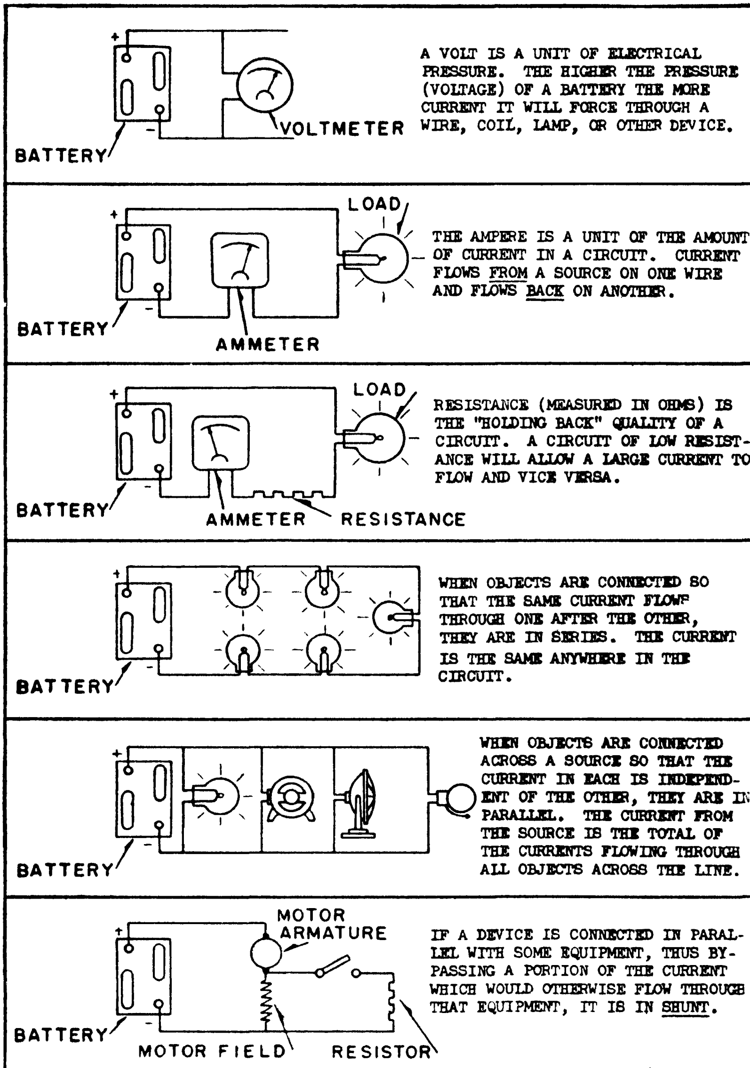
As the motor speed continues to increase, the generator voltage increases again closing the transition relay. The relay then operates the shunting contactors which connect resistors across the motor fields, lowering the generator voltage. If train speed continues to increase, the transition relay remains closed.

When train speed decreases, first the transition relay drops out, opening the shunting contactors. Further reduction in speed has no effect on the transition relay, so to bring the motors to their original connection (series) the throttle must be brought to idle.

Refer to "Motor Control" Plate, Fig. 3, for the electrical apparatus involved in transition.

The following items refer in general to all units except where specified.

Main Generator. Directly connected to the engine crankshaft through a flexible coupling, this supplies the electrical energy used



EXPLANATION OF ELEMENTARY ELECTRICAL TERMS

Fig. 1

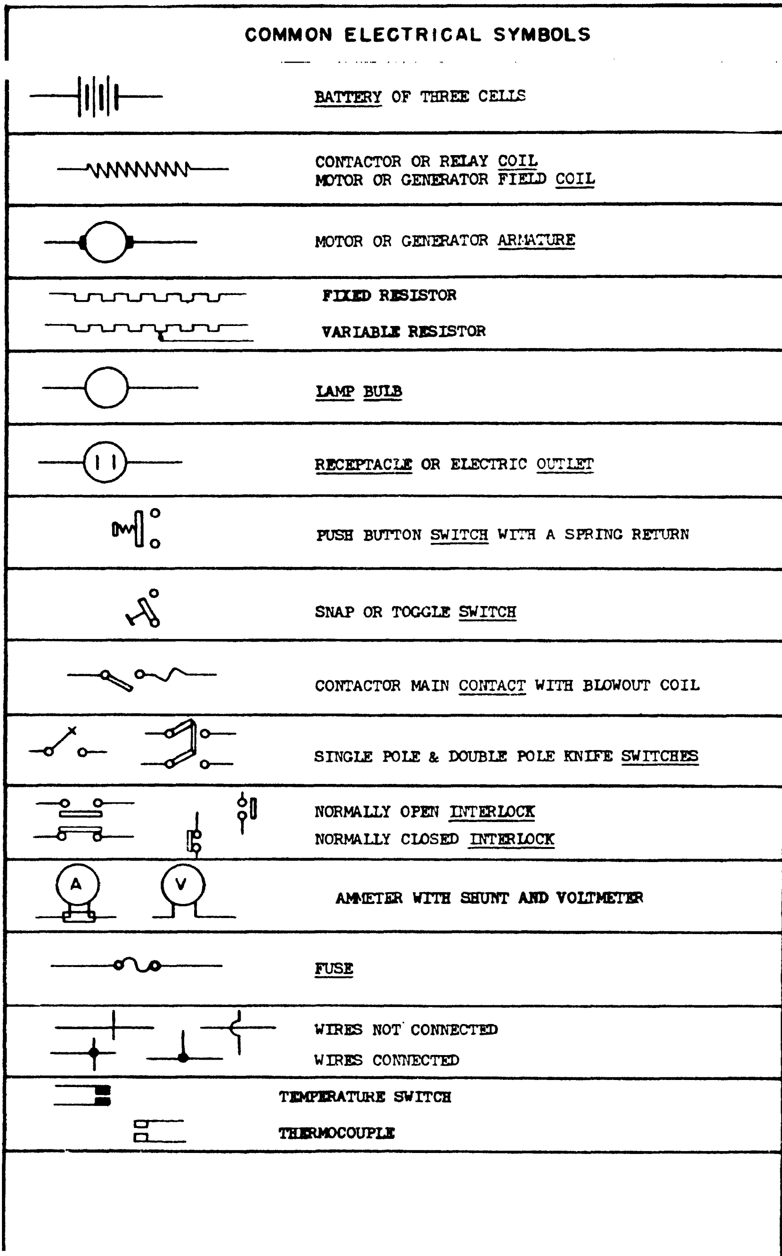

COMMON ELECTRICAL SYMBOLS
BATTERY OF THREE CELLS
CONTACTOR OR RELAY COIL
MOTOR OR GENERATOR FIELD COIL
MOTOR OR GENERATOR ARMATURE
FIXED RESISTOR
VARIABLE RESISTOR
LAMP BULB
RECEPTACLE OR ELECTRIC OUTLET
PUSH BUTTON SWITCH WITH A SPRING RETURN
SNAP OR TOGGLE SWITCH
CONTACTOR MAIN CONTACT WITH BLOWOUT COIL
SINGLE POLE & DOUBLE POLE KNIFE SWITCHES
NORMALLY OPEN INTERLOCK
NORMALLY CLOSED INTERLOCK
A
V
AMMETER WITH SHUNT AND VOLTMETER
FUSE
WIRES NOT CONNECTED
WIRES CONNECTED
TEMPERATURE SWITCH
THERMOCOUPLE

Fig. 2

to move the locomotive. The main generator also serves to crank the Diesel engine for starting by the use of special starting fields energized from the battery.

Auxiliary Generator. This 10 KW generator is belt-driven from the main generator and charges the battery. With the battery charging, the current exciting the main generator, running the fuel pump, operating the control equipment and the lights, is actually coming from the auxiliary generator. However, its primary purpose is as a charger and not as an exciter.

Traction Motors. These four direct-current, roller bearing motors supply all of the power used to move the locomotive. The two motors in each truck are permanently connected in series.

Isolating One Truck—1000 Hp. In re-railing a locomotive or in the event a traction motor becomes defective, one or both trucks can be isolated electrically by the motor cut-out switches mounted in the high voltage cabinet.

MC01 is a double pole, double throw switch for isolating the No. 1 (front) truck, and MC02 is the same type of switch for isolating the No. 2 (rear) truck. The normal position of the switch is up. To cut out a truck, the switch for that truck is thrown to the down position, the switch for the other truck being left in its normal position. When one or both of the switches is left, that is, not making contact with either the upper or lower contacts—the locomotive will be unable to move under its own power. Both switches should not be down.

Any person throwing a motor cut-out switch should clearly understand that it is to be done in case of extreme necessity and that the locomotive must not handle any cars with a truck cut out. Do not operate in more than ½ throttle with a truck isolated.

Traction Motors (600 Hp. Only). These four direct-current, roller bearing motors supply all of the power used to move the locomotive. The four motors are permanently connected in series.

To Isolate the No. 1 Truck. Remove cable A1 at the line contactor and completely insulate the end of the cable with electrical insulating tape of some kind. Next, disconnect cable A3 from the reverser and connect it by means of a jumper cable to the binding post on the line contactor where cable A1 was connected. A

jumper cable approximately 4 or 5 feet long and capable of carrying main generator current will be required.

To Isolate the No. 2 Truck. Remove cable A3 from the reverser and completely insulate the end of the cable with electrical insulating tape of some kind. Then connect a jumper cable—from the A3 binding post on the reverser to the A- binding post on the reverser. This will require a jumper cable about 18 inches long and capable of carrying main generator current.

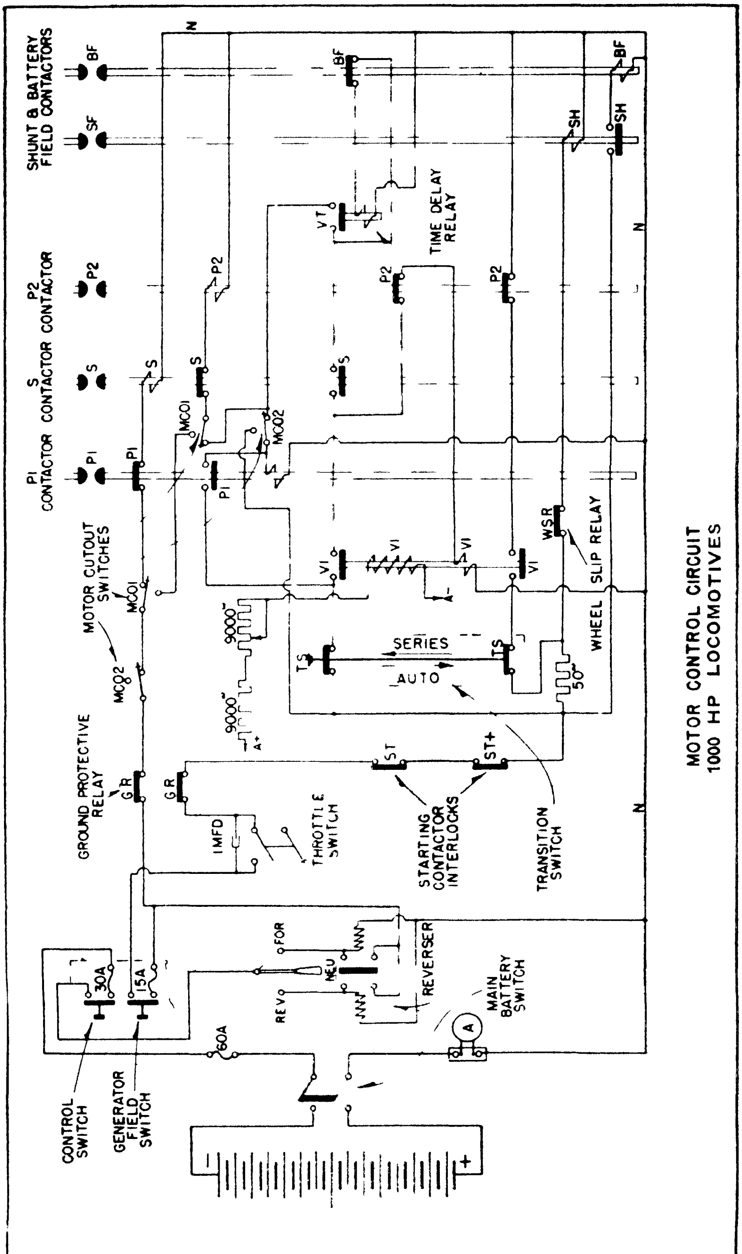
Warning. Isolating a truck should be done only in case of extreme necessity, such as where one truck is off the rails and it is necessary to use the other truck to help re-rail the locomotive, or where a traction motor is disabled and it is necessary for the locomotive to travel to the round house or shop under its own power. Under no condition should the locomotive be allowed to do any switching or handling of cars with one truck cut out. The danger is that of ruining the other traction motors by overloading.

Controller. The controller or control station contains the throttle handle and reversing handle. The throttle handle is connected mechanically to the engine governor, which in turn controls the speed of the engine. The reversing handle operates electric contacts which allow current to operate either the forward or reverse magnet valves on the reverser in the high voltage cabinet. There is no connection between the reversing handle and the reverser if the electrical circuit is open. See the wiring diagrams for details.

Reverser. This air operated reversing switch changes the direction of flow of the current through the traction motor fields, thus causing the motors to rotate in the opposite direction. The direction of current never reverses in the generator.

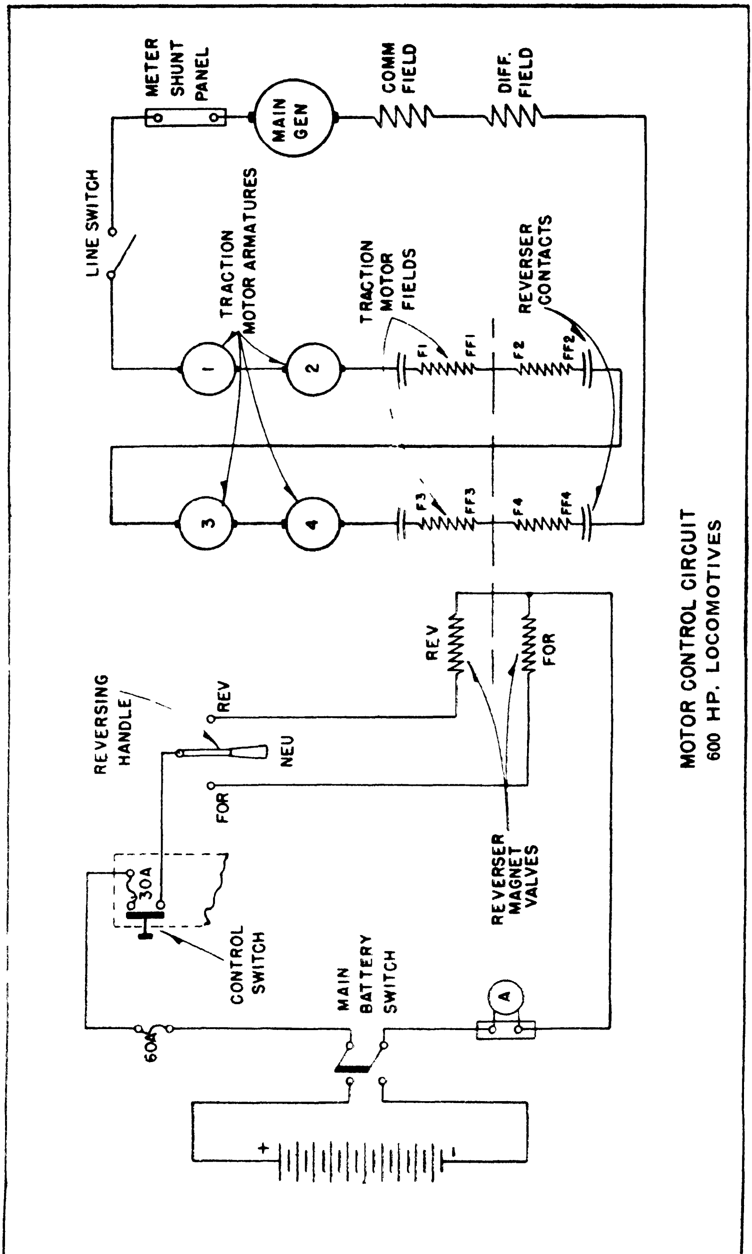
Motors, Other Than Traction. Two small motors are used: one drives the fuel pump, the other the cab heater. They are similar in construction but differ in size.

Traction Motor Contactors "P1", "P2", and "S". These contactors change the traction motor connections from series to series-parallel or vice versa. These switches operate on air pressure through magnet valves. Be sure the arc chutes are securely in place at all times. (Used on 1000 hp. and 1350 hp. units.)



MOTOR CONTROL CIRCUIT
1000 HP LOCOMOTIVES

Fig 3



MOTOR CONTROL CIRCUIT
600 HP. LOCOMOTIVES

Fig. 4

Engine Starting Contactor. These contactors close when the engine start switch is closed, connecting the battery to the main generator, causing the generator to become a motor to crank the Diesel engine. Interlocks on these contactors prevent the generator from delivering power when the starting contactors are closed.

Battery Charging Contactor. This contactor operated by the reverse current relay, closes to connect the battery to the auxiliary generator when its voltage is high enough to force current into the battery.

Battery Field Contactor. This contactor connects the battery to the main generator battery field, through the load regulator.

Generator Shunt Field Contactor. This contactor connects the generator shunt field to the generator armature, through the shunt field resistor.

Reverse Current Relay. This relay prevents the battery current from motoring the auxiliary generator by opening the battery charging contactor when the auxiliary generator voltage drops below the battery voltage.

Voltage Regulator. This maintains the output of the auxiliary generator at a constant voltage regardless of the speed of the engine or the gravity of the battery. This keeps the battery charged and provides a constant source of excitation for the main generator.

The setting of the voltage regulator must be determined for each individual locomotive according to the service it is in. For the first few weeks after a new locomotive is put in service, the batteries should be checked at frequent intervals and the voltage regulator adjusted to maintain proper battery gravity of 1230 to 1250. Too low a setting will cause the battery voltage to drop and too high a setting will cause the batteries to gas. Experience has shown that the voltage regulator should be set at approximately 74 volts.

Current Limit Relay. This relay is connected in series with the main generator output and operates when current in this line reaches 1550 amperes. The relay lights the wheel slip light indicating that the engineer should close the throttle, bringing the motors to their series position. (Adjustment shown for 1000 hp. unit.)

Load Regulator and Pilot Valve Operation. The load regulator is the rheostat in series with the generator battery field which controls the load on the engine.

Ground Protective Relay. If a ground occurs in the high voltage system, the relay opens the battery, shunt field and traction motors contactors. If this happens, bring the engine to idle and reset the relay by pushing in on the insulated button provided for emergency. If the relay repeatedly opens when the engine speed is increased, proper authority should be notified at once. In extreme emergency, the locomotive may be operated with great caution by making the relay inoperative. To do this, open the knife switch located in the high voltage cabinet. This relay is very important to safe locomotive operation and its function must not be abused.

Wheel Slip Relay. This relay operates when a wheel slips with power on, because one of its two solenoids becomes energized and pulls on the contact armature.

When the relay operates it flashes the wheel slip light and opens the generator field contactors, causing the wheels to stop slipping. The relay then drops back, closing the generator field contactors which may cause the wheels to slip again. Therefore, the wheel slip light will flash intermittently in contrast to the generator overload indication which is a steady glowing of the wheel slip light.

Throttle Switch. This switch opens the generator shunt and battery field circuits when the throttle is at idle.

Lighting and Control Switches. These are the pushbutton switches. The lighting switch box, above the sanding valve in the cab, contains the following circuits:

Headlight Front (Dim)	Number Lights
Headlight Rear (Dim)	Gauge Lights
Cab Lights	

The control switch box on the control stand contains the following circuits:

Control	Fuel Pump
Generator Field	Engine Start
Cab Heater	

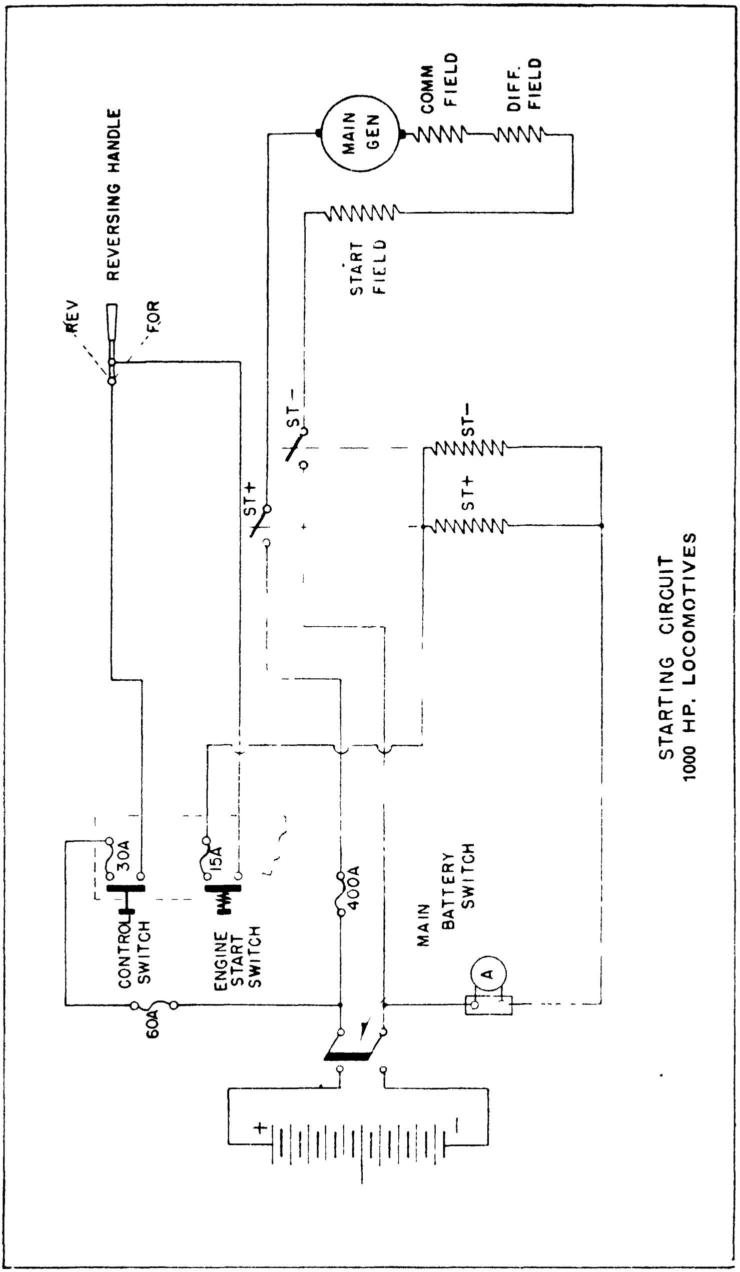
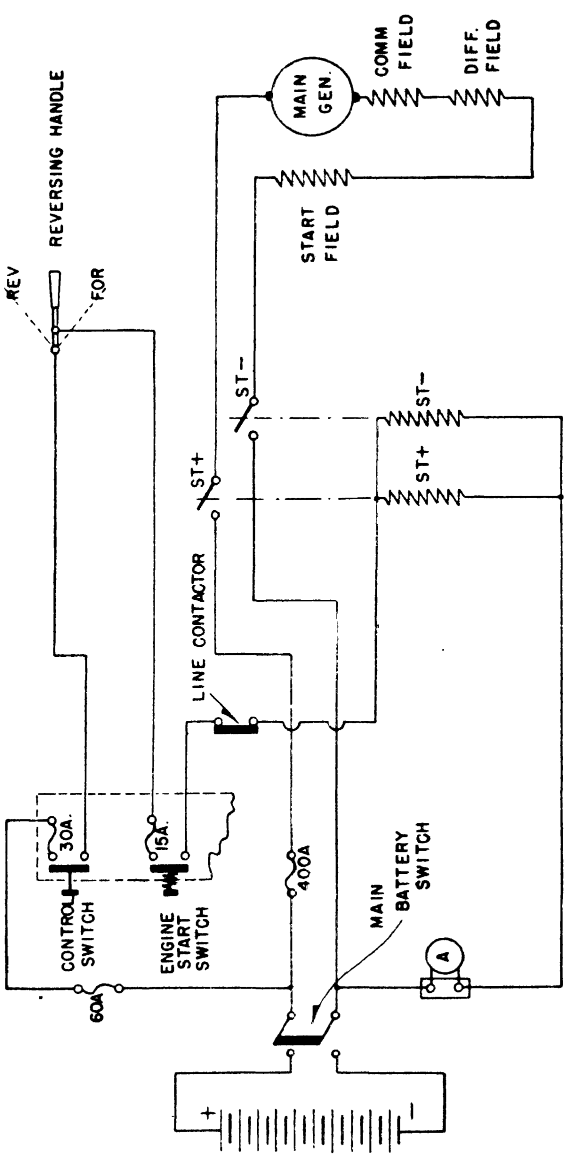

REVERSING HANDLE
REV
FOR
MAIN GEN
COMM FIELD
DIFF. FIELD
START FIELD
ST–
ST+
ST–
ST+
30A
15A
CONTROL SWITCH
ENGINE START SWITCH
400A
MAIN BATTERY SWITCH
A
60A
+
–
STARTING CIRCUIT
1000 HP. LOCOMOTIVES

Fig. 5



STARTING CIRCUIT
600 HP. LOCOMOTIVES

Fig. 6

Main Battery Switch. This isolates all circuits from the battery except the battery neutral wire and the external charging receptacle. Keep the blades lubricated with a thin film of petroleum jelly so that the switch can be operated easily.

Ground Relay Switch. This opens the circuit to the operating coil of the ground relay. See paragraph on "Ground Protective Relay."

Headlight Control Switch. This switch located above the sanding valve operates either headlight to make it bright or medium. Only one light is affected at a time. The headlight push-button switches over the sanding valve also must be operated. The push-button switches turn the headlights on the dim position.

Oil Shut-Down Magnet Valve. This valve dumps the oil from the oil shut-down cylinder in the event the piston cooling low oil pressure switch closes, thus bringing the engine to idle.

Battery. The locomotive storage battery has 32 cells. Gravity should be checked once weekly and should be between 1230 and 1250. Use only distilled water to fill the battery and keep water level up to 1 inch above top of plates. Be careful not to get any of the battery fluid on yourself or the battery. This is sulphuric acid, and is extremely corrosive. To counteract the acid should it splash on clothing, put a strong solution of baking soda and water on the area affected. Do not use water only to wash off acid.

Keep the battery terminals covered with a thin film of petroleum jelly to prevent corrosion from the battery vapors.

Inspect the cells through the filler holes after the engine has been running continually for some time. Violent bubbling should be reported. If the battery requires more than just a small quantity of water, report this to the maintainer. If the battery is being overcharged, it will boil off the water, become overheated and even become short-circuited internally.

Battery Charging Resistor. Connected in series with the output of the auxiliary generator, this resistor prevents overload to the auxiliary generator (too high a charging rate). The voltage regulator is not a current regulator, so in the event the battery was discharged or internally short-circuited, this resistor prevents a burn-

out of the auxiliary generator, if the current is not sufficient to burn out the auxiliary generator fuse.

Shunt Field Resistor. These tubes are connected in series with the generator shunt field. They simply limit the shunt field current. No adjustment is necessary.

Shunt Field Discharge Resistor. This resistor is shorted out when the shunt field contactor is closed. It prevents burning of the shunt field contactor contacts or damage to the generator due to the high inductive voltage which might otherwise occur if the contactor was opened with the generator running at top speed.

Battery Field Discharge Resistor. This resistor shunts the main generator battery field to prevent high voltage induction when the battery circuit to the field is opened.

Lamp Series Resistors. In series with the number light and wheel slip light, these resistors drop the voltage to 32 volts to these lights.

Wheel Slip Resistors (Fixed and Adjustable). The adjustable tube balances the inner coil to the outer coil. The four fixed resistors form a bridge so that unless a wheel slips there is no current flowing through the relay.

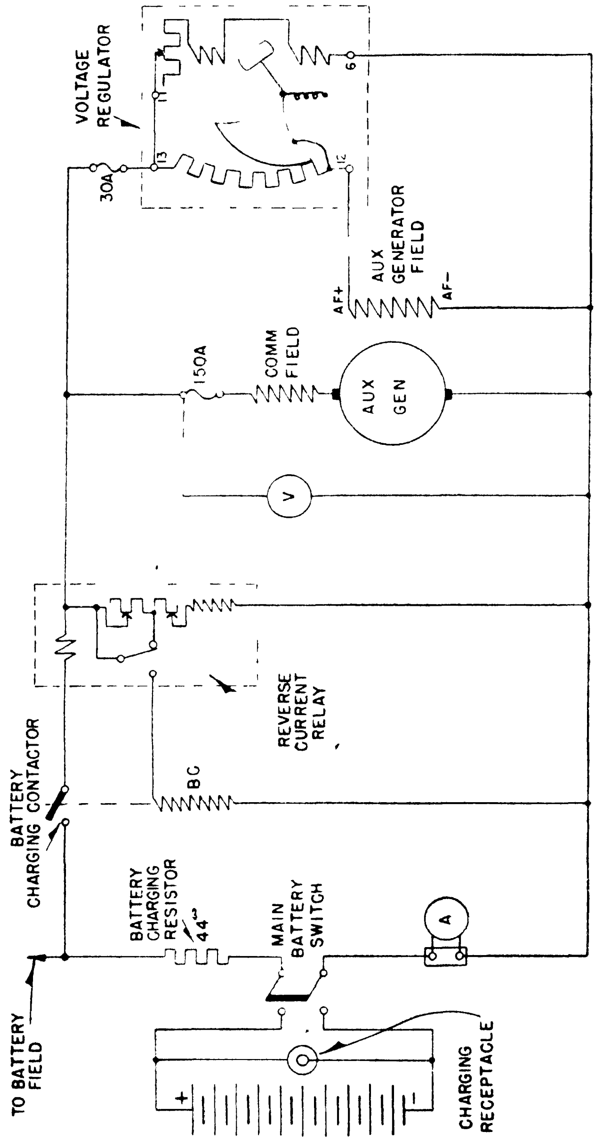
Headlight Resistors (Adjustable). These are connected to the headlight dimming switch to steady the headlights when on bright and drop the voltage for medium and dim.

Transition Relay Resistors. One resistor is fixed, the other is adjustable. These drop the main generator voltage before it reaches the operating coil of the transition relay.

Meters. The voltmeter and ammeter are on the low voltage panel. If the voltmeter remains at zero, it is an indication that the auxiliary generator 150 ampere armature fuse, or 30 ampere field fuse, has burned out.

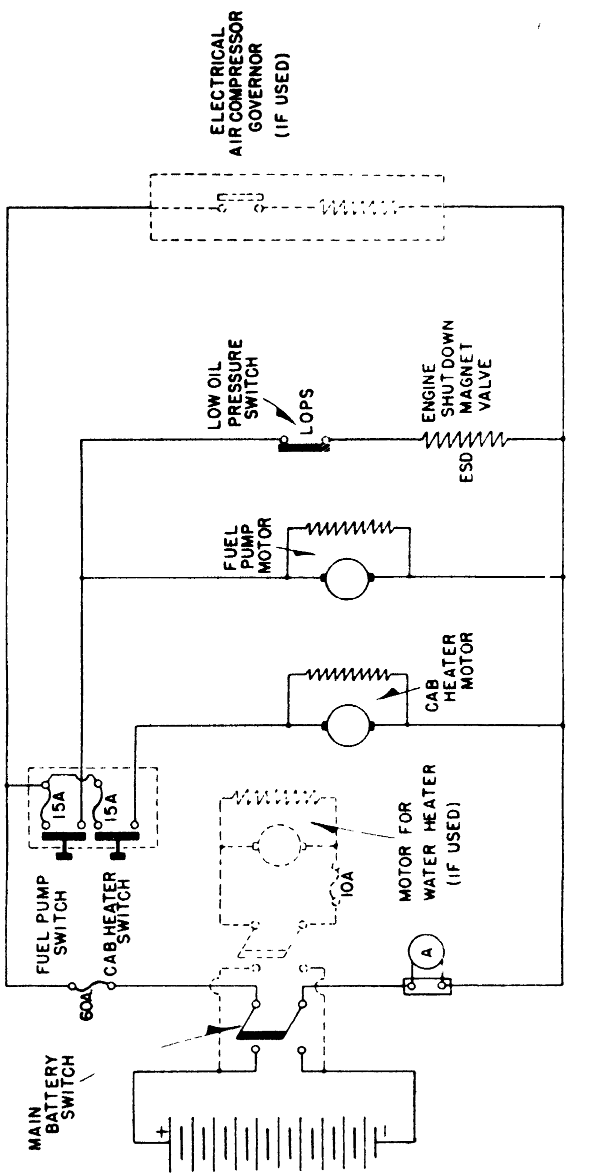
A defective voltage regulator will be evidenced by excessive fluctuations of the ammeter and voltmeter. Broken or loose **V**-belts will affect the charging rate and the excitation of the main generator.

Tachometer. The Jones-Motrola tachometer is mechanical and requires no servicing other than lubrication.



BATTERY CHARGING CIRCUIT
1000 HP. LOCOMOTIVES

Fig. 7



ELECTRICAL ACCESSORIES CIRCUIT
600 AND 1000 HP. LOCOMOTIVES

Fig. 8

Battery Charging Receptacle. Connected directly across the battery is the external charging receptacle. An ammeter in the external charging equipment must be used as a check on the charging rate. The main battery switch can be either open or closed, for with the power plants shut down, the reverse current relay opens the auxiliary generator charging circuit.

Headlights. The two headlights are 14 inches, 100 watt, 32 volts.

Fuses. Never remove an auxiliary generator fuse with the engine running. Never pull any fuse unless the switch to that circuit is open. The inductive current in some circuits is sufficient to seriously injure a person.

Motor Control Circuit Explanation. Before the locomotive will move, the following switches must be closed: Main battery switch, control switch, and generator field switch. The reversing handle and reverser must be in forward or reverse position. The throttle must be in advanced position.

Forward Transition. (Transition not on 600 hp. unit.)

1. *Idle to Series Transition* (Starting the Locomotive)

(a) Moving reversing handle closes *S* contactor through *P1* Interlock.

(b) Opening throttle closes *SF* contactor (providing the ground, starting, and wheel slip relay Interlocks are closed.)

(c) *BF* contactor closes through *SF* Interlock.

2. *Series to Series-Parallel Transition* (Approx. 10 m.p.h.)

(a) Transition Relay *V1* picks up.

(b) Transition Relay holding coil is energized through *V1* and *P2* Interlocks.

(c) Transition Relay closing drops *SF* and *BF* Contactors.

(d) *VT* Relay closes through *V1*, *S*, and *BF* Interlocks.

(e) *P1* Contactor closes through *VT* Interlocks.

(f) *P1* Contactor holds through *P1* Interlock.

(g) *S* Contactor opens through *P1* Interlock.

(h) *S* opening closes *P2* Contactor.

(i) *P2* Interlock opening closes *SF* and *BF* Contactors, and opens Transition Relay holding coil and *VT* Relay.

To return the motors to the series position the throttle must

first be closed and then opened. Closing the throttle opens *SF*, *BF*, *P1* and *P2* contactors. *S* contactor then closes and opening the throttle closes *SF* and *BF* contactors. The motors are then in series.

Jumper Cable (16 Conductor) (2000 Hp. Unit Only). This cable carries the following circuits between locomotive units:

No.	Code	Circuit	No.	Code	Circuit
1	OS	Oil Signal	9	RE	Reverse
2	SG	Signal	10	WS	Wheel Slip
3	DV	D-Valve	11	BA	Boiler Alarm
4	N	Negative	12	BV	B-Valve
5	TS	Temperature Signal	13	PC	Positive Control
6	GF	Generator Field	14	SN	Signal Negative
7	CV	C-Valve	15	AV	A-Valve
8	FO	Forward	16	FP	Fuel Pump

Hot Journal Alarm Thermocouples. Refer to Fig. 30 of this chapter.

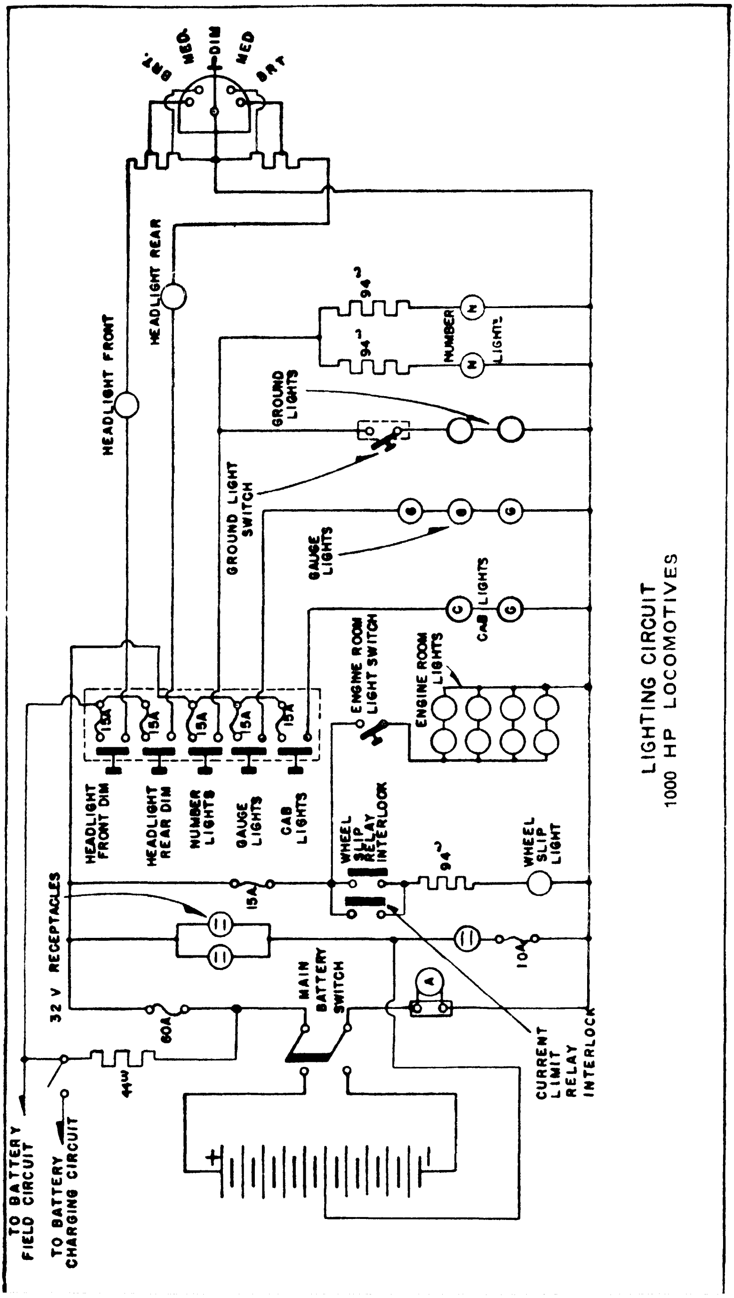
When Alarm Gong Operates. 1. Stop train. Determine which unit is sounding gong. All gongs sound but hot journal indicator lights in defective unit only. Look for hot journal. If journal is hot, examine for cause and correct trouble or, if advisable, proceed with caution.

2. If journal is not hot but gong continues to ring, before reaching terminal check for a defective relay, fuse, or loose wire. If it is determined that a defective thermocouple is causing the gong to ring, proceed to the terminal and locate the thermocouple as outlined in paragraphs 4 and 5 following.

3. It may be necessary to silence the gong. If so, open bell cutout switch *A*. This will not interfere with hot journal alarm on other unit or other alarms on any unit.

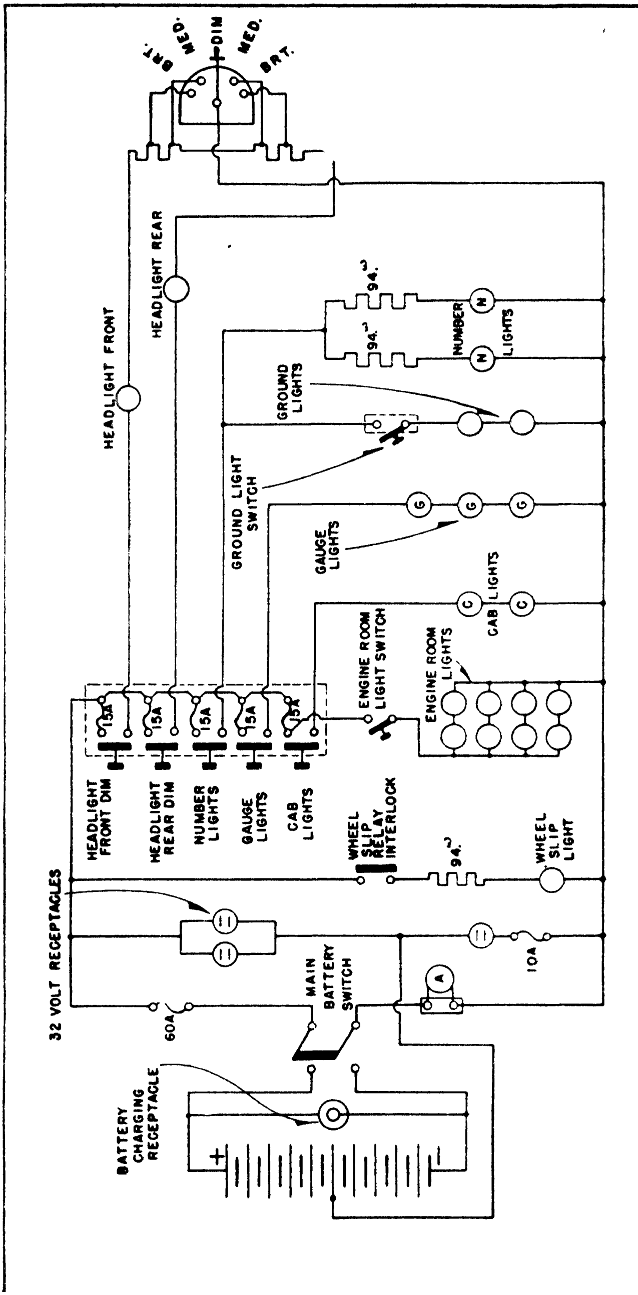
4. To determine the truck in which a thermocouple is open, remove rubber jumper from truck to locomotive and insert the short-circuited tester plug (8004923) into the locomotive receptacle *C*. If alarm gong stops sounding, proceed to check individual thermocouple as in next paragraph.

5. With gong sounding, insert the tester plug into each thermocouple receptacle *D* until the gong stops ringing. Never operate the locomotive with tester plug in receptacle as this prevents the thermocouple on that journal from functioning.



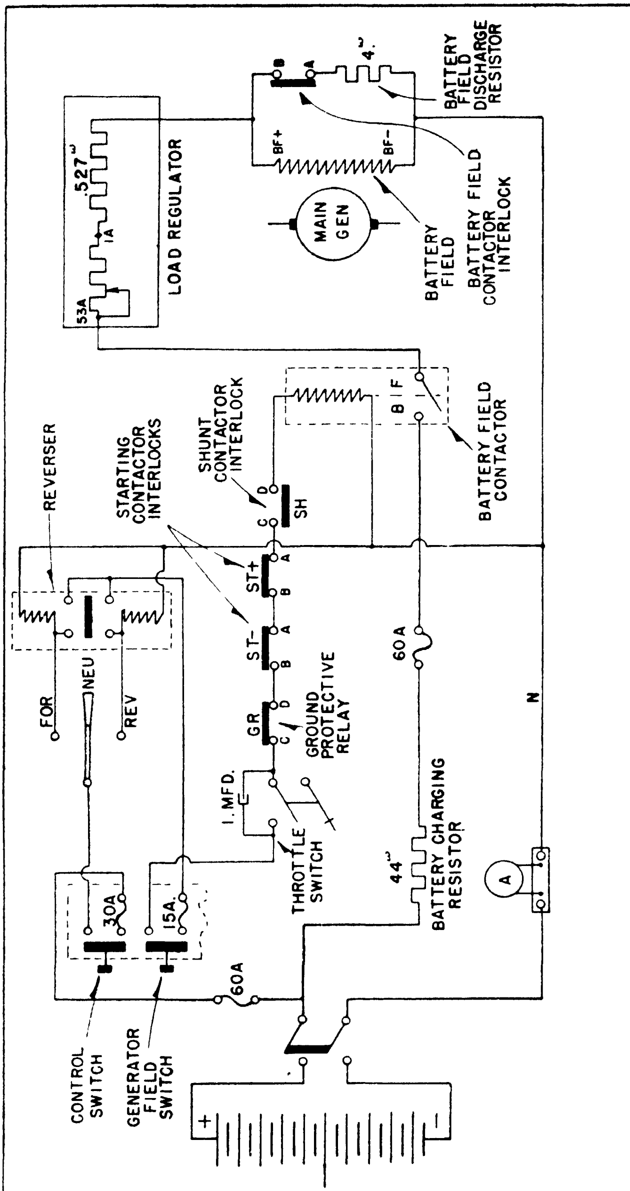
LIGHTING CIRCUIT
1000 HP LOCOMOTIVES

Fig 9



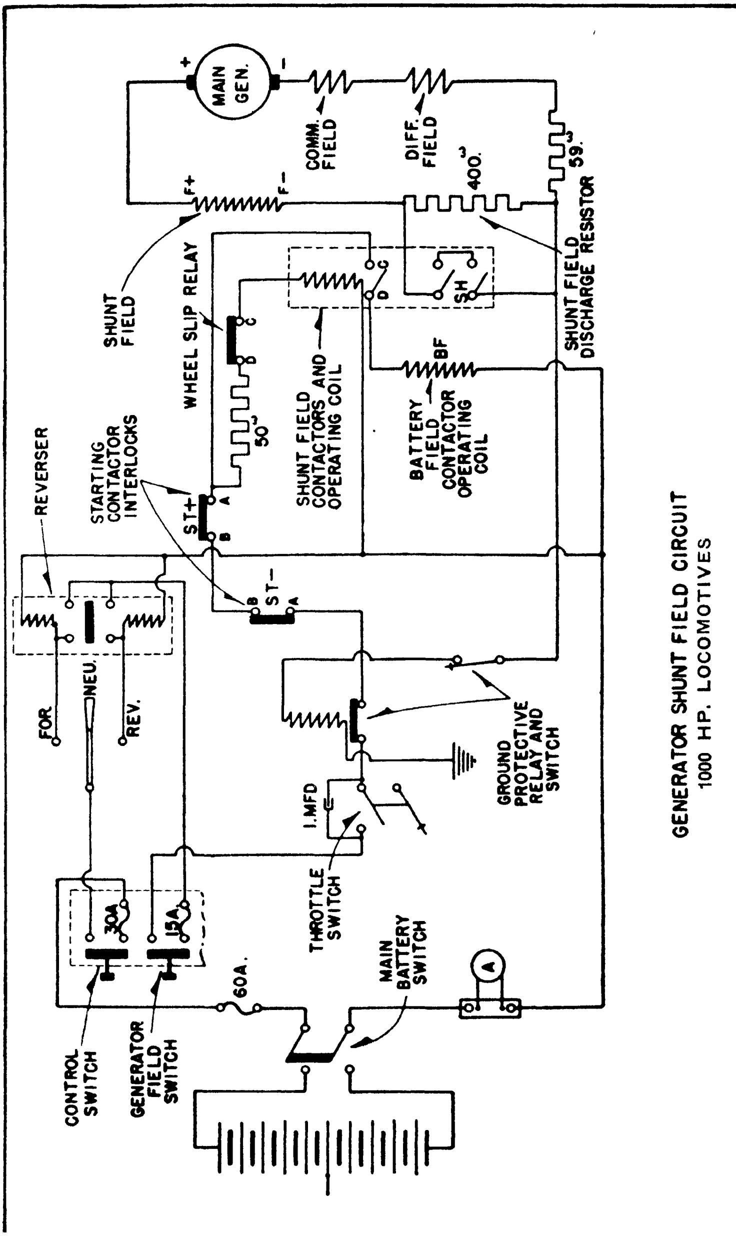
LIGHTING CIRCUIT
600 HP. LOCOMOTIVES

Fig. 10



GENERATOR BATTERY FIELD CIRCUIT
1000 HP. LOCOMOTIVES

Fig. 11



GENERATOR SHUNT FIELD CIRCUIT
1000 HP. LOCOMOTIVES

Fig. 12

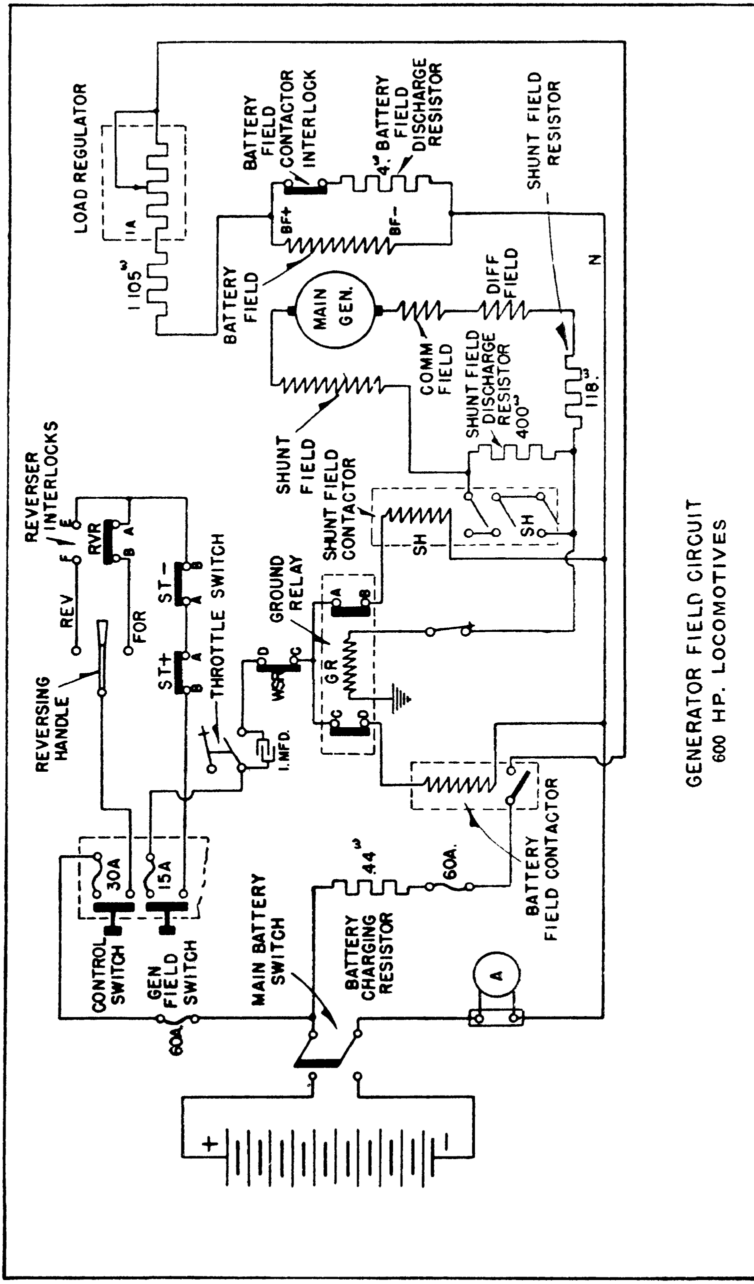

LOAD REGULATOR
1A
1.105Ω
BATTERY FIELD CONTACTOR INTERLOCK
4Ω BATTERY FIELD DISCHARGE RESISTOR
SHUNT FIELD RESISTOR
BF+
BF-
BATTERY FIELD
MAIN GEN.
DIFF FIELD
COMM FIELD
N
SHUNT FIELD DISCHARGE RESISTOR 400Ω
1.18Ω
SHUNT FIELD
SHUNT FIELD CONTACTOR
SH
REVERSER INTERLOCKS
RVR
REV
FOR
ST-
ST+
THROTTLE SWITCH
GROUND RELAY
GR
WSR
1.MFD.
REVERSING HANDLE
30A
15A
CONTROL SWITCH
GEN FIELD SWITCH
60A
MAIN BATTERY SWITCH
BATTERY CHARGING RESISTOR
.44Ω
60A.
BATTERY FIELD CONTACTOR
A
GENERATOR FIELD CIRCUIT
600 HP. LOCOMOTIVES

Fig. 13

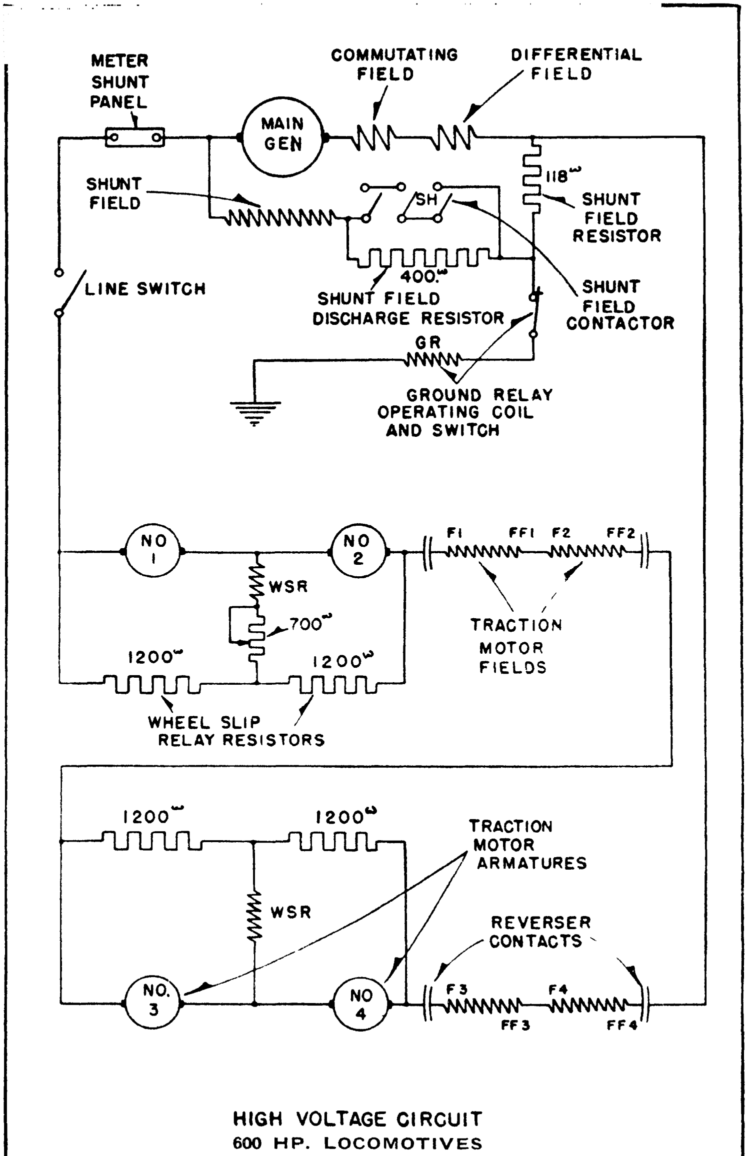

METER SHUNT PANEL
COMMUTATING FIELD
DIFFERENTIAL FIELD
MAIN GEN
118
SHUNT FIELD RESISTOR
SHUNT FIELD
SH
400
SHUNT FIELD DISCHARGE RESISTOR
LINE SWITCH
SHUNT FIELD CONTACTOR
GR
GROUND RELAY OPERATING COIL AND SWITCH
NO 1
NO 2
F1
FF1
F2
FF2
WSR
700
1200
1200
TRACTION MOTOR FIELDS
WHEEL SLIP RELAY RESISTORS
1200
1200
TRACTION MOTOR ARMATURES
WSR
REVERSER CONTACTS
NO. 3
NO 4
F3
F4
FF3
FF4
HIGH VOLTAGE CIRCUIT
600 HP. LOCOMOTIVES

Fig. 14

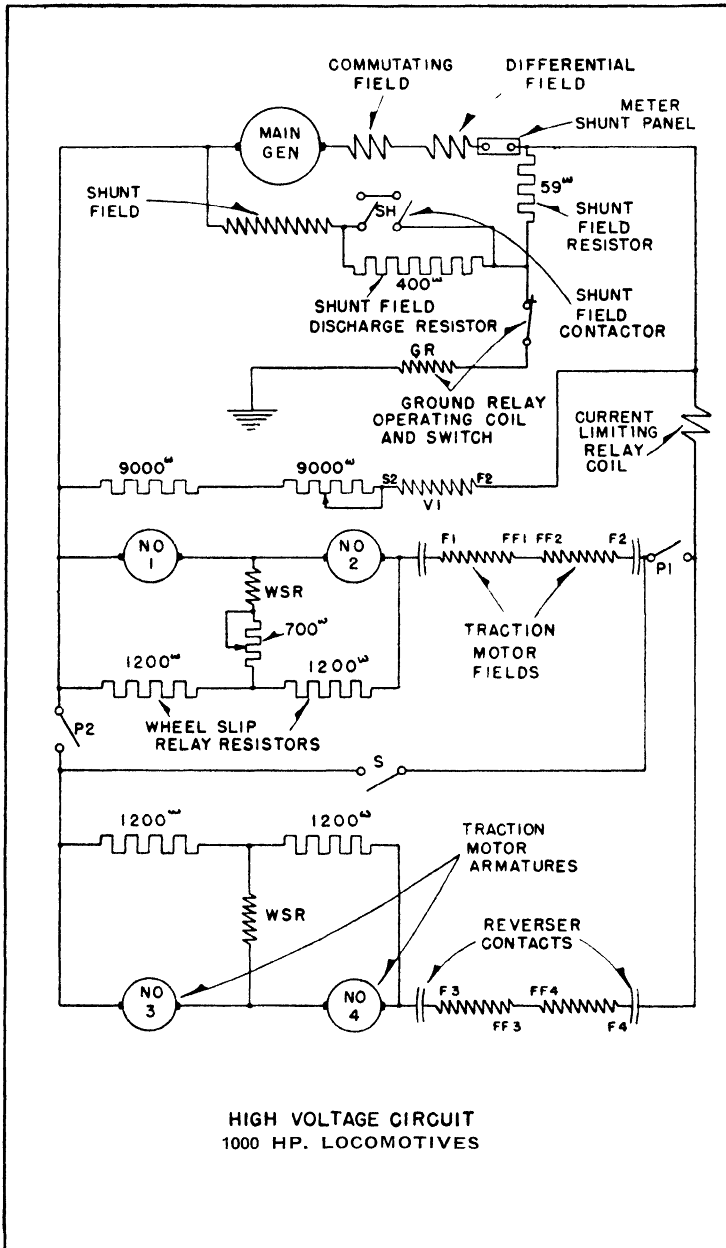

COMMUTATING FIELD
DIFFERENTIAL FIELD
METER SHUNT PANEL
MAIN GEN
59ω
SHUNT FIELD
SH
SHUNT FIELD RESISTOR
400ω
SHUNT FIELD DISCHARGE RESISTOR
SHUNT FIELD CONTACTOR
GR
GROUND RELAY OPERATING COIL AND SWITCH
CURRENT LIMITING RELAY COIL
9000ω
9000ω
S2
F2
V1
NO 1
NO 2
F1
FF1 FF2
F2
P1
WSR
700ω
TRACTION MOTOR FIELDS
1200ω
1200ω
P2
WHEEL SLIP RELAY RESISTORS
S
1200ω
1200ω
TRACTION MOTOR ARMATURES
WSR
REVERSER CONTACTS
NO 3
NO 4
F3
FF4
FF3
F4
HIGH VOLTAGE CIRCUIT
1000 HP. LOCOMOTIVES

Fig. 15

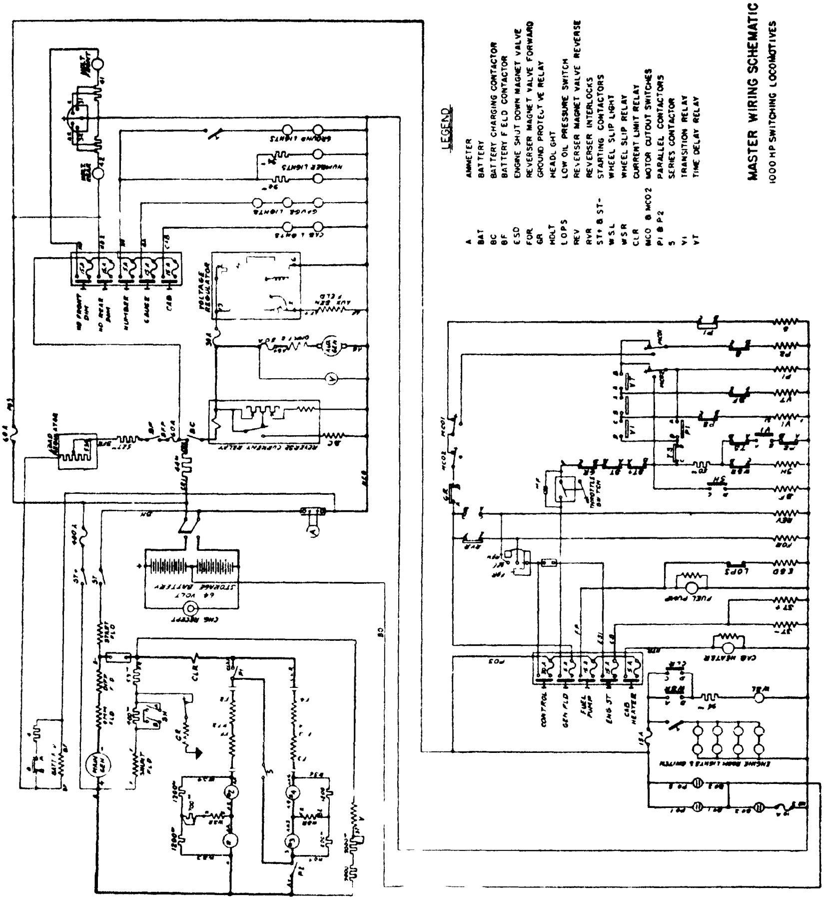

MASTER WIRING SCHEMATIC
1000 HP SWITCHING LOCOMOTIVES
LEGEND
A AMMETER
BAT BATTERY
BC BATTERY CHARGING CONTACTOR
BF BATTERY FIELD CONTACTOR
ESD ENGINE SHUT DOWN MAGNET VALVE
FOR REVERSER MAGNET VALVE FORWARD
GR GROUND PROTECTIVE RELAY
HDLT HEADLIGHT
LOPS LOW OIL PRESSURE SWITCH
REV REVERSER MAGNET VALVE REVERSE
RVR REVERSER INTERLOCKS
ST+ & ST- STARTING CONTACTORS
WSL WHEEL SLIP LIGHT
WSR WHEEL SLIP RELAY
CLR CURRENT LIMIT RELAY
MCO & MCO2 MOTOR CUTOUT SWITCHES
P1 & P2 PARALLEL CONTACTORS
S SERIES CONTACTOR
V1 TRANSITION RELAY
VT TIME DELAY RELAY

Fig. 16

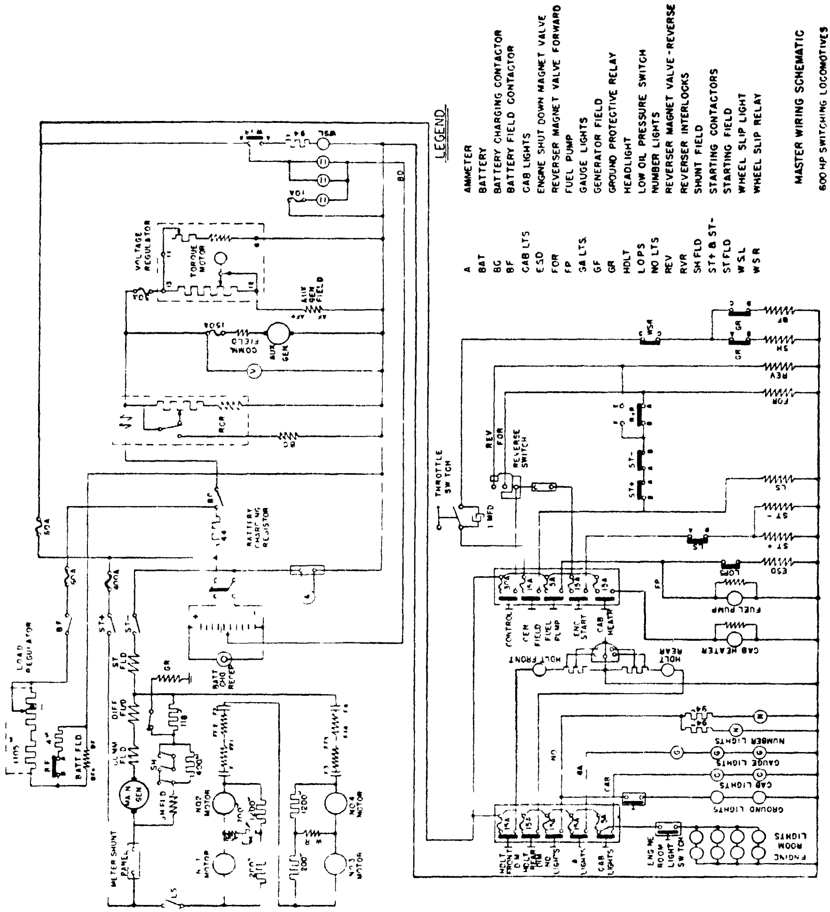
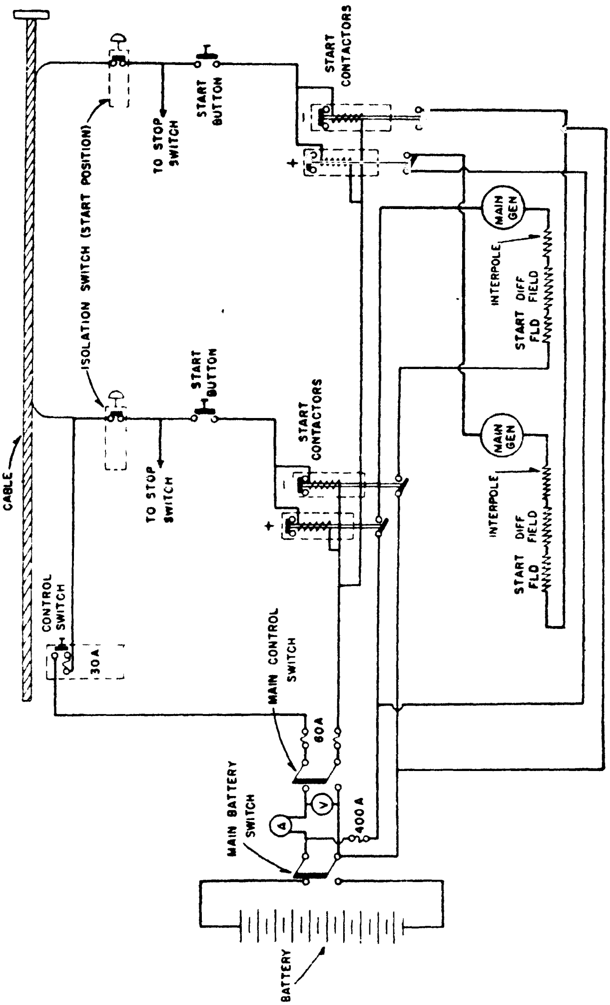
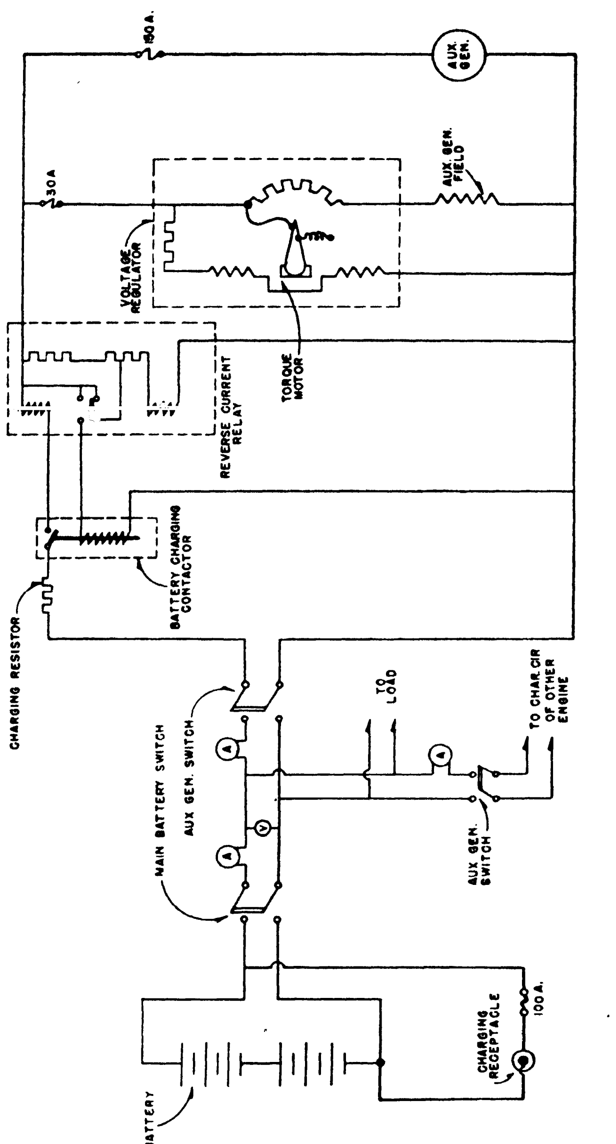

LEGEND
A AMMETER
BAT BATTERY
BC BATTERY CHARGING CONTACTOR
BF BATTERY FIELD CONTACTOR
CAB LTS CAB LIGHTS
ESD ENGINE SHUT DOWN MAGNET VALVE
FOR REVERSER MAGNET VALVE FORWARD
FP FUEL PUMP
GA LTS GAUGE LIGHTS
GF GENERATOR FIELD
GR GROUND PROTECTIVE RELAY
HDLT HEADLIGHT
LOPS LOW OIL PRESSURE SWITCH
NO LTS NUMBER LIGHTS
REV REVERSER MAGNET VALVE-REVERSE
RVR REVERSER INTERLOCKS
SH FLD SHUNT FIELD
ST+ & ST- STARTING CONTACTORS
ST FLD STARTING FIELD
WSL WHEEL SLIP LIGHT
WSR WHEEL SLIP RELAY
MASTER WIRING SCHEMATIC
600 HP SWITCHING LOCOMOTIVES

Fig. 17



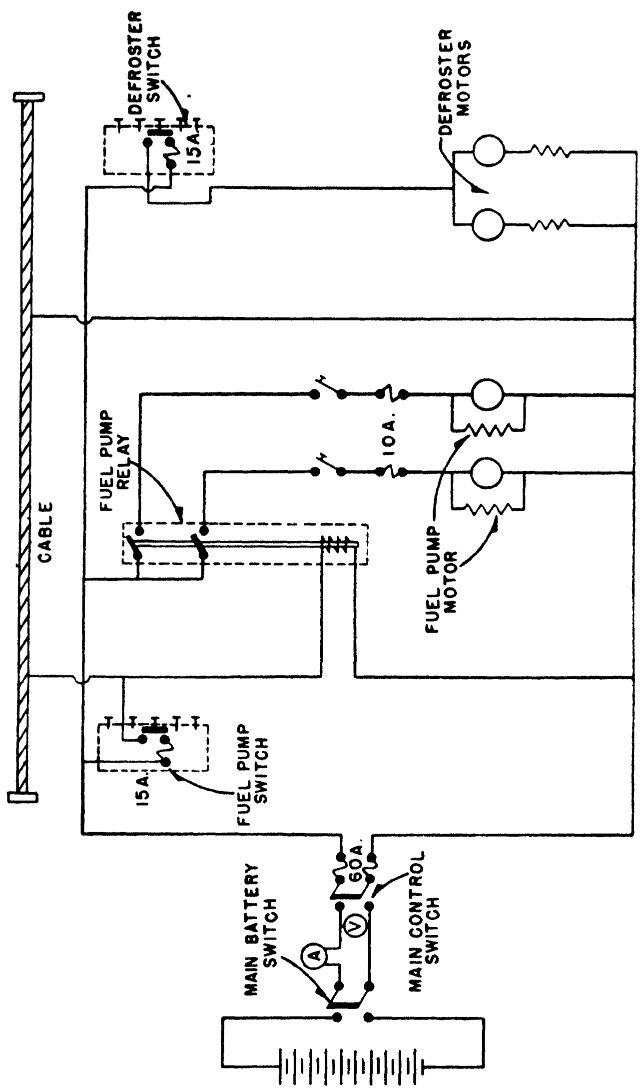
STARTING CIRCUIT
2000 HP. LOCOMOTIVES

Fig. 18



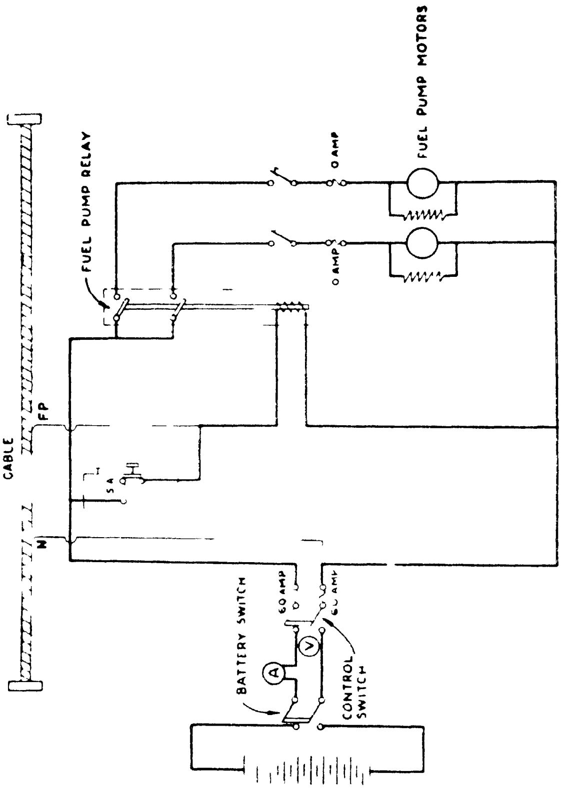
BATTERY CHARGING CIRCUIT
2000 HP. LOCOMOTIVES

Fig. 19



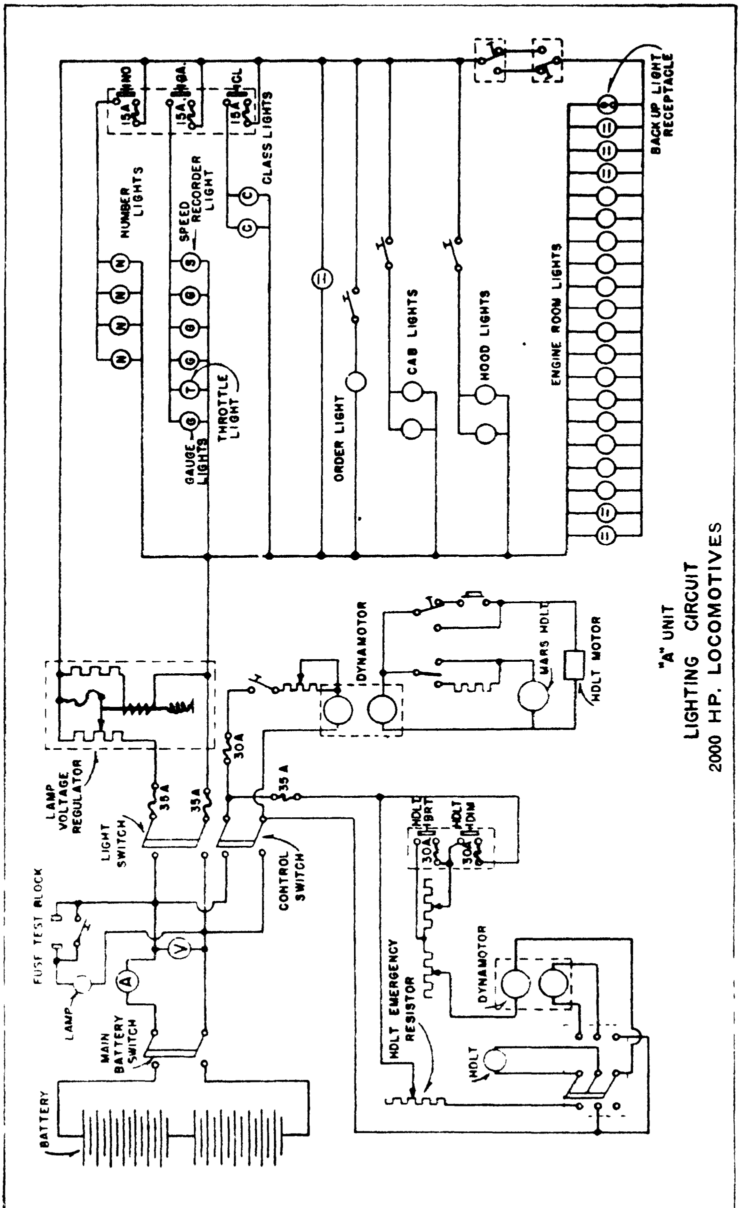
"A" UNIT
FUEL PUMP & DEFROSTER CIRCUIT
2000 HP. LOCOMOTIVES

Fig. 20



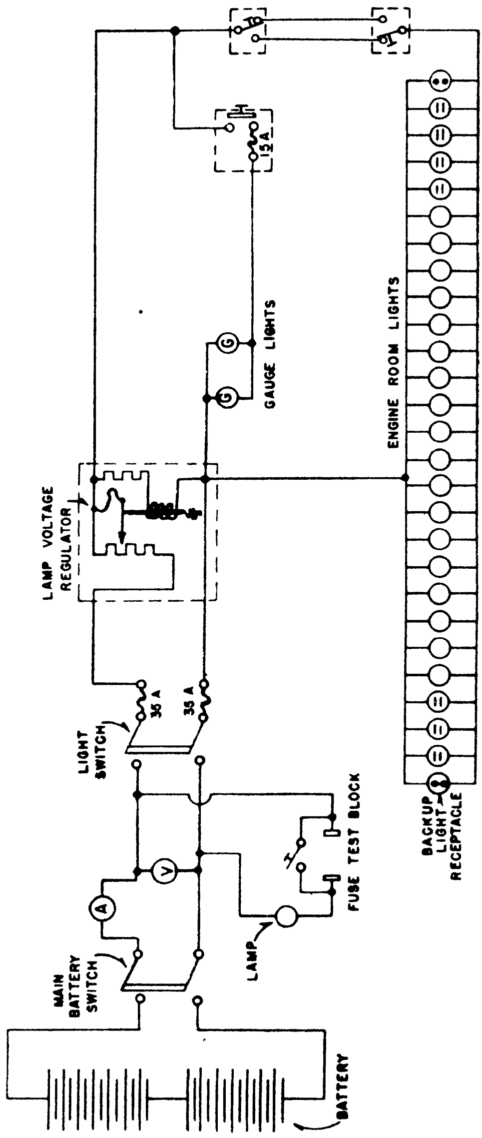
FUEL PUMP CIRCUIT
B UNIT
2000 HP. LOCOMOTIVES

Fig 21



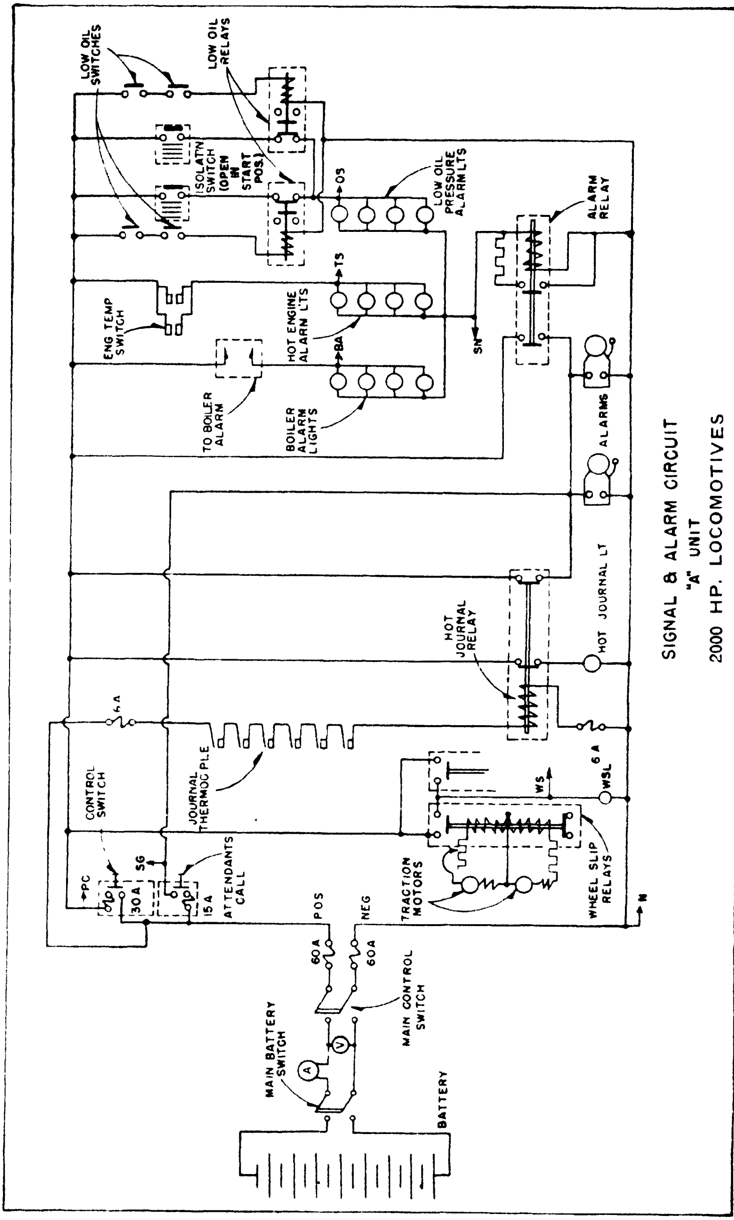
"A" UNIT
LIGHTING CIRCUIT
2000 HP. LOCOMOTIVES

Fig. 22



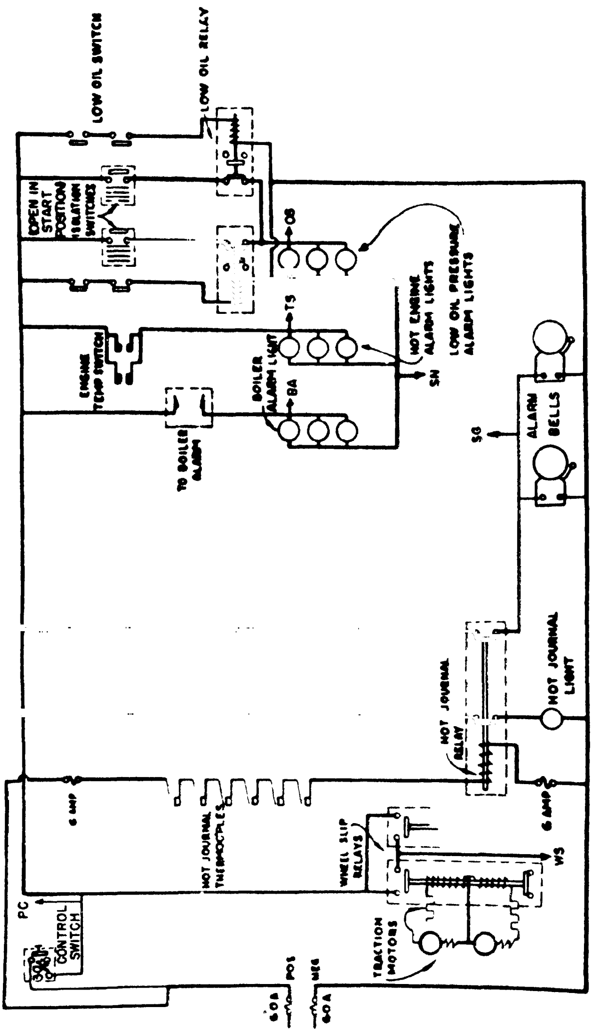
"B" UNIT
LIGHTING CIRCUIT
2000 HP. LOCOMOTIVES

Fig. 23



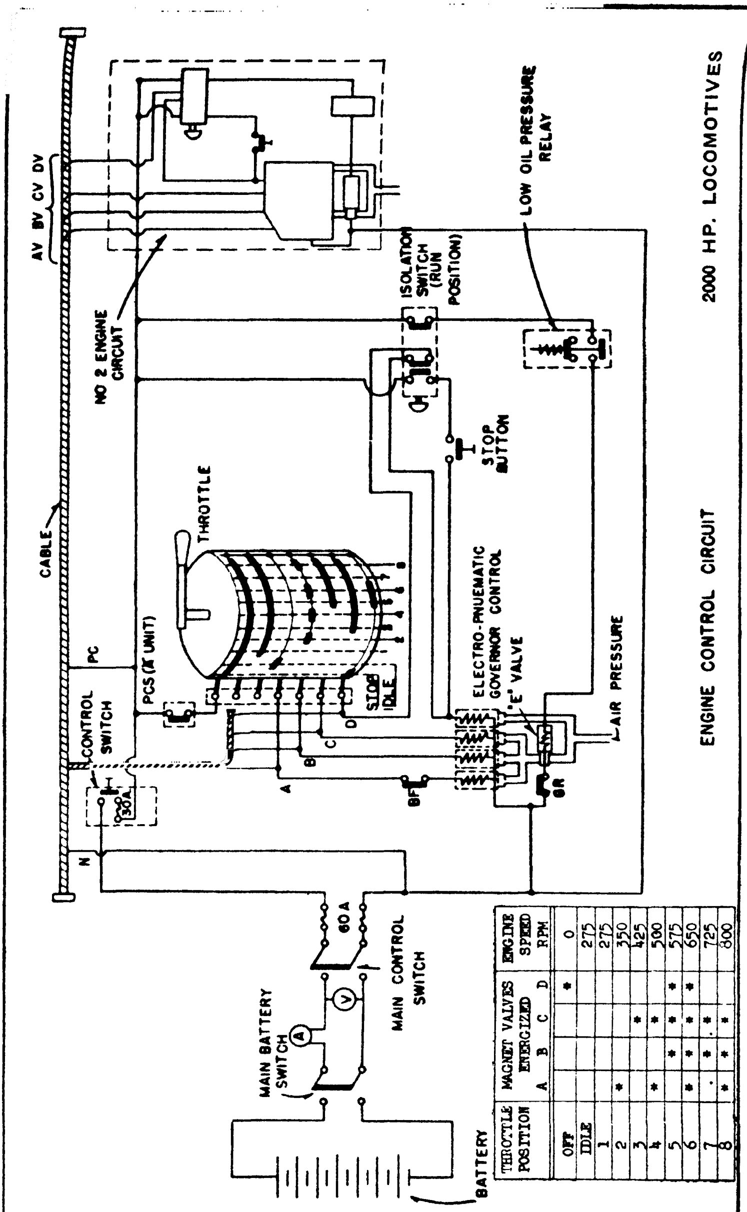
SIGNAL & ALARM CIRCUIT
"A" UNIT
2000 HP. LOCOMOTIVES

Fig. 24



SIGNAL AND ALARM CIRCUIT
"B" UNIT
2000 HP. LOCOMOTIVES

Fig. 25



THROTTLE POSITION	MAGNET VALVES ENERGIZED A	B	C	D	ENGINE SPEED RPM
OFF				*	0
IDLE					275
1					275
2	*				350
3			*		425
4	*		*		500
5		*	*	*	575
6	*	*	*	*	650
7	.	*	*		725
8	*	*	*		800

Fig. 26

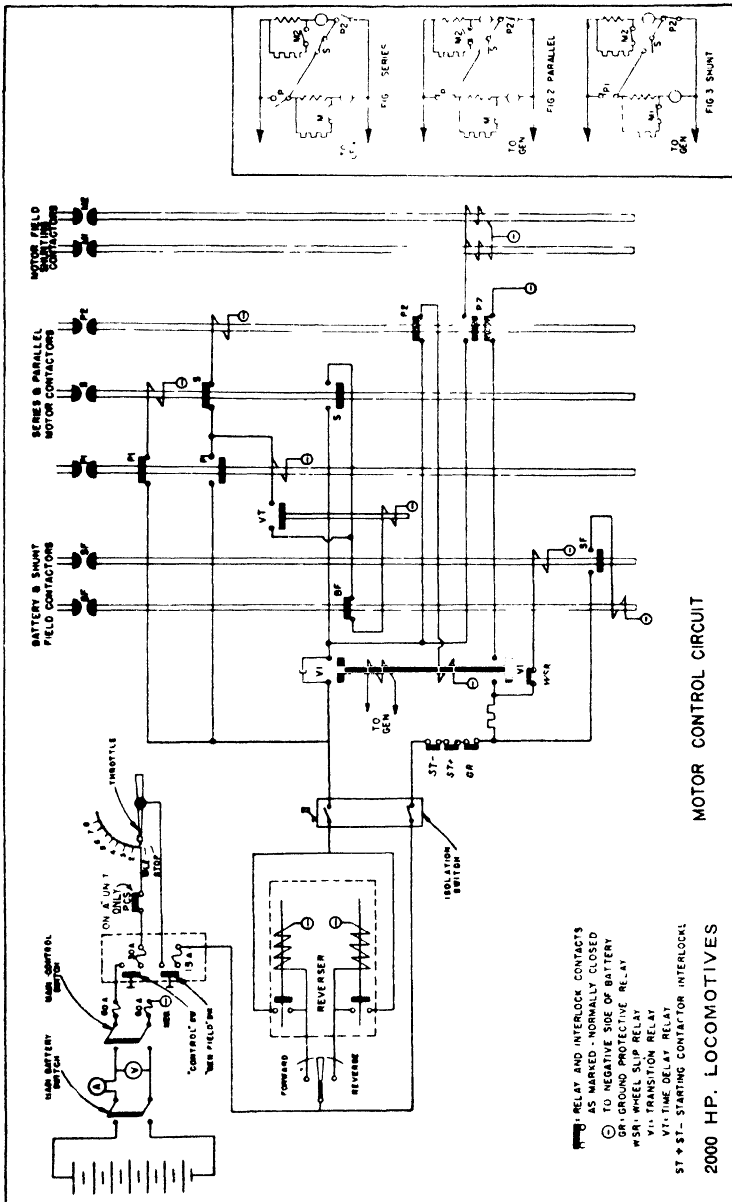
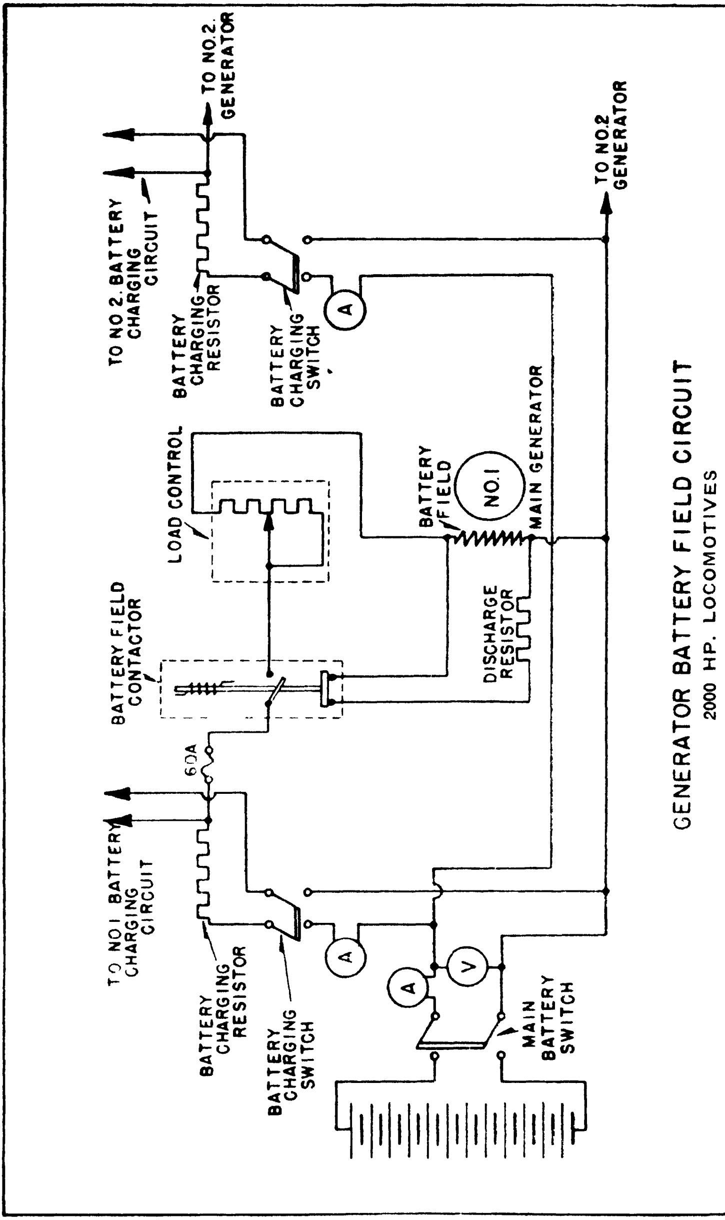


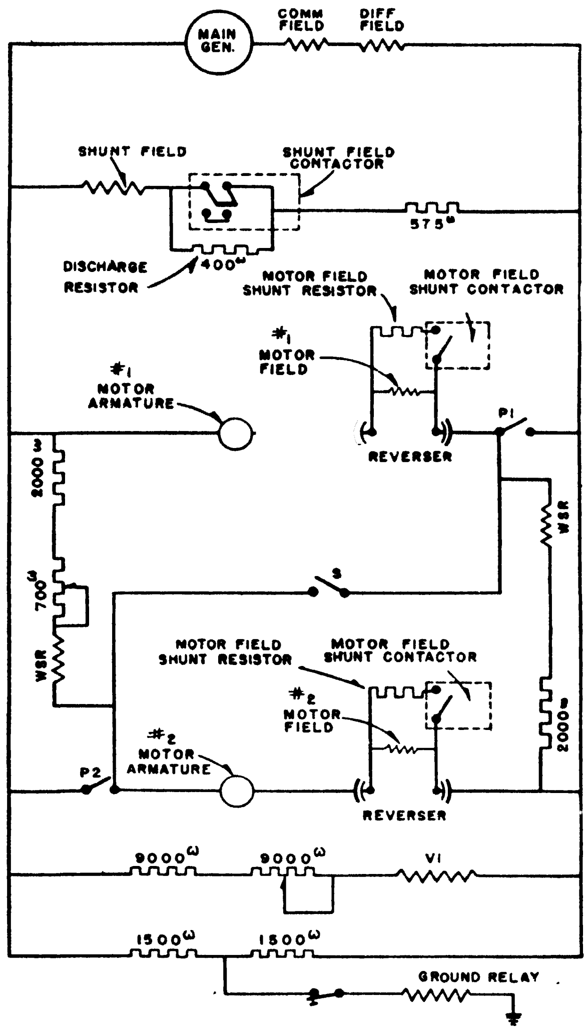
FIG 1 SERIES
FIG 2 PARALLEL
FIG 3 SHUNT
TO GEN
MOTOR FIELD SHUNTING CONTACTORS
SERIES & PARALLEL MOTOR CONTACTORS
BATTERY & SHUNT FIELD CONTACTORS
THROTTLE
STOP
ON "A" UNIT ONLY
PCS
ISOLATION SWITCH
REVERSER
FORWARD
REVERSE
MAIN BATTERY SWITCH
MAIN CONTROL SWITCH
"CONTROL" SW
"GEN FIELD" SW
ST-
ST+
GR
WSR
TO GEN
MOTOR CONTROL CIRCUIT
RELAY AND INTERLOCK CONTACTS AS MARKED - NORMALLY CLOSED
TO NEGATIVE SIDE OF BATTERY
GR: GROUND PROTECTIVE RELAY
WSR: WHEEL SLIP RELAY
VI: TRANSITION RELAY
VT: TIME DELAY RELAY
ST + ST- STARTING CONTACTOR INTERLOCKS
2000 HP. LOCOMOTIVES

Fig. 27



GENERATOR BATTERY FIELD CIRCUIT
2000 HP. LOCOMOTIVES

Fig. 28



HIGH VOLTAGE CIRCUIT
2000 HP. LOCOMOTIVES

Fig 29

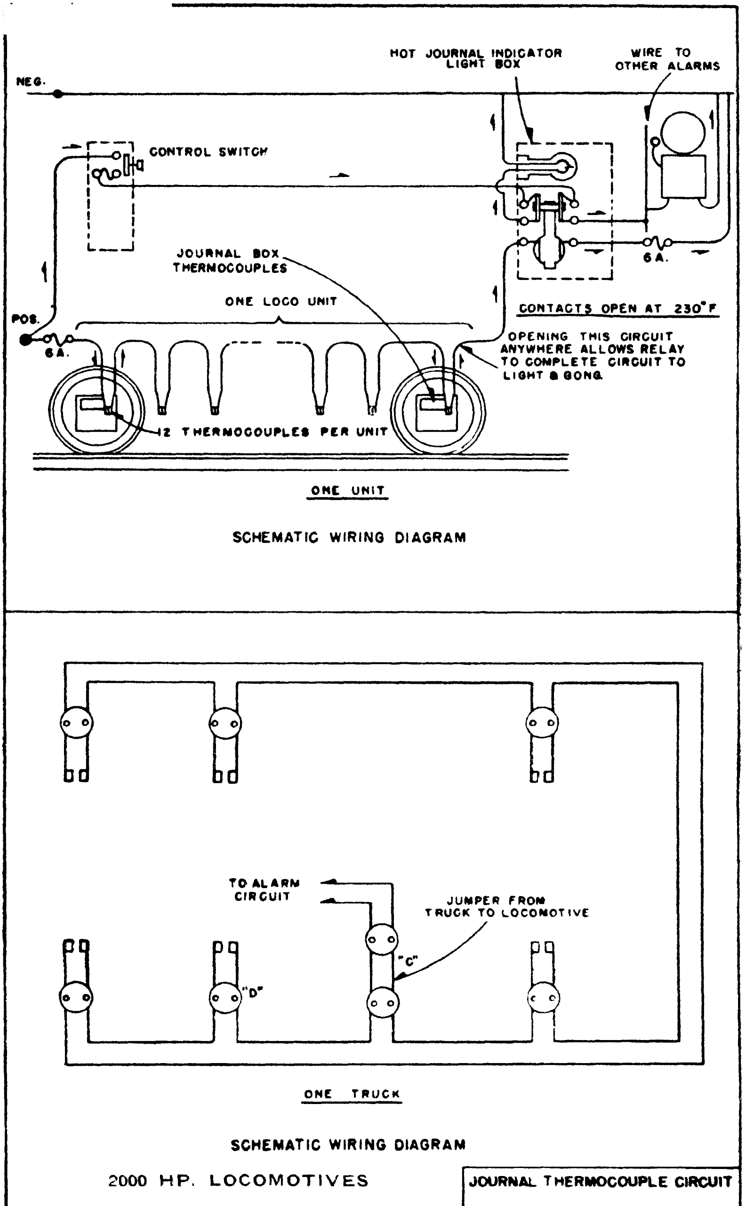
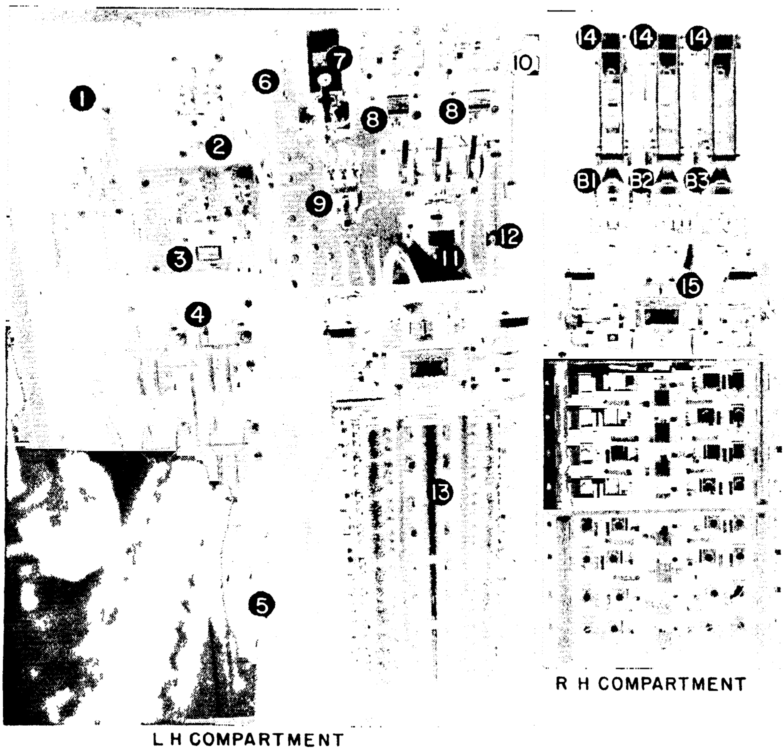

HOT JOURNAL INDICATOR LIGHT BOX
WIRE TO OTHER ALARMS
NEG.
CONTROL SWITCH
JOURNAL BOX THERMOCOUPLES
ONE LOCO UNIT
POS.
6A.
6A.
CONTACTS OPEN AT 230°F
OPENING THIS CIRCUIT ANYWHERE ALLOWS RELAY TO COMPLETE CIRCUIT TO LIGHT & GONG
12 THERMOCOUPLES PER UNIT
ONE UNIT
SCHEMATIC WIRING DIAGRAM
TO ALARM CIRCUIT
JUMPER FROM TRUCK TO LOCOMOTIVE
"C"
"D"
ONE TRUCK
SCHEMATIC WIRING DIAGRAM
2000 HP. LOCOMOTIVES
JOURNAL THERMOCOUPLE CIRCUIT

Fig. 30



2700 Freight Unit

1 Time Delay Relay
2 Brake Relay
3 Field Loop Contactor
4 Motor Shunting Contactors
5 Transition Meter Shunt

6 Ground Relay Switch
7 Ground Relay
8 Wheel Slip Relay
9 Parallel Relay
10 Shunt Field Discharge Resistor

11 Shunt Field Contactor
12 Shunt Field Contactor Resistor (50 0 Ohm)
13 Reverser
14 Braking Contactors
15 Cam Switch

Chapter IX

ALCO-GE 660 HP. AND 1000 HP. DIESEL-ELECTRIC LOCOMOTIVES

MAINTENANCE. Maximum service can be obtained from electric equipment only when it is kept dry and clean. This is especially true when oil, copper dust, brake shoe dust, or other metallic matter may collect in or about the apparatus.

All apparatus should be blown out using clean, dry compressed air; and accessible parts should be wiped off with dry waste or clean wiping rags. Washed wiping rags are preferable to cotton waste as they are less liable to leave lint. When using air for cleaning in the vicinity of exposed mica insulation, care should be taken not to use too high pressure or get the nozzle too close or small flakes of mica will be blown off finally resulting in complete destruction of the insulation.

Oil is very destructive to insulating materials as it collects dust and dirt causing them to break down electrically. When lubricating apparatus extreme care should be taken to prevent the lubricant from getting on insulated parts, and if any does get on it should be immediately and thoroughly wiped off with clean wiping rags.

All screws, bolts and nuts which secure electrical connections should be kept tight to insure good contact. When making a ground connection the surface to which connection is to be made should be thoroughly cleaned of all dirt, paint or rust to assure good electrical contact.

Cement may be used to advantage in repairing burned insulation such as sides of arc chutes, contactors, and switches.

Glyptal No. 1201 varnish is recommended for all cables exposed to dirt or moisture, especially where creepage is important.

When painting control apparatus use a good quality of insulating varnish.

Be sure that tools, bolts, nuts, etc., are not left on or around

TABLE 1. ELECTRICAL EQUIPMENT LUBRICATION CHART‡

The following lubrication requirements are based on average conditions. It is recommended that a regular greasing schedule be established for the particular service requirements by keeping careful records and thereby determining the necessary quantities and time intervals or mileages.

Name of Parts	Lubricant Recommended	Schedule
Reverser		
Grease Fitting	Cup Grease	1 to 2 turns monthly
Contacts	*Stazrite No. 30 or equal	Thin film at inspections
Cylinders and Piston Packing	G-E PC Control Lubricant No. 2	Keep well greased
Traction Generator		
Main Bearing	G-E Ball Bearing Grease	3 oz. every 6 months
GMG. Set		
Bearings	G-E Ball Bearing Grease	¼ oz. every 6 months
Traction Motor		
Armature Bearings	G-E Ball Bearing Grease	2 oz. C.E. bearing annually †4 oz. P.E. bearing annually
Waste Pocket-Axle Bearing	Long Fibre All Wool Waste	Repack every 25/30.000 miles For procedure see Traction Motor Instructions
Axle Bearings	Good Grade Electric Car Oil	Check oil level every 3000 miles Maintain 1¾ in. to 3½ in. measured on slant
Gear Case	Texas Crator Compound or equal (No. 5 for Summer, No. 2 for Winter)	Keep teeth well covered

Radiator Fan Gear Box		
Vertical Shaft Bearing	G-E Ball Bearing Grease	1 oz. every 6 months
Horizontal Shaft Bearing	G-E Ball Bearing Grease	3 oz. every 6 months
Housing	Crank case oil (SAE-40 Grade)	Check monthly. Drain and refill annually
Controller		
Segments	*Stazrite No. 30 or equal	Thin film at inspections
Bearings	Machine Oil	A few drops at inspections
Cams (M-U Loco. only)	*Stazrite No. 30 or equal	Thin film at inspections
Pneumatic Contactors		
Oil hole in cylinder	G-E PC Control Lubricant No. 1	A few drops monthly
Piston Leathers	G-E PC Control Lubricant No. 1	Soften with oil at overhaul periods
Cylinders	G-E PC Control Lubricant No. 2	Grease at overhaul periods
Throttle Operating Mechanism (M-U Loco. only)		
Oil Holes in Cylinders	G-E PC Control Lubricant No. 1	A few drops monthly
Hinge and Lever Pins	Machine Oil	Keep well lubricated
Cylinders and Piston Leathers	G-E PC Control Lubricant No. 2	Grease at overhaul periods
Fuel Pump Motor	G-E Ball Bearing Grease	Clean and repack bearings annually
Push Button Control Switch		
Segments	*Stazrite No. 30 or equal	Thin film at inspections

‡Refer to Alco Switcher Lubrication Chart.
†4 oz. every 6 months on Road-Switcher.
*Product of Quaker Chemical Products Corp., Conshohocken, Pa.

the frames of the electrical equipment. Serious damage may result from an oversight of this nature.

During inspections the following should be watched for and corrected:

Loose screws and nuts.

Cotter pins missing or not split.

Broken or weak springs.

Grease, oil, or dirt on insulating material, contacts or any current carrying parts.

Worn or burned contacts.

Loose terminals and connections.

Broken insulators.

Loose tie rods on resistors.

Read each section of these instructions carefully before attempting to do any work.

ICC High Potential Tests. Refer to Locomotive Connection Diagram. To conform with the ICC requirements as given in paragraph No. 253 of the "Laws, Rules and Instructions for Inspection and Testing of Locomotives other than Steam," periodic high potential tests are required on electrical circuits and windings carrying current of potential over 150 volts. (This applies only to locomotives engaged in interstate service).

Preparation. To prepare the locomotive for these tests, proceed as follows:

1. The electric circuits and windings to be tested should be prepared as necessary by cleaning, painting or repairing.

2. Open battery switch 100 and ground relay switch 108.

3. Tie wire 65C to ground at GSS with No. 12 B & S wire.

4. On locomotives equipped with ammeters in the power circuits, disconnect the ammeter leads at the shunt.

5. Place jumpers across (or insert a piece of metal between) contact tips of contactors *S*, *SP1*, and *SP2*.

6. Manually set the reverser for either forward or reverse direction.

7. See that engine starting contactors *GS1* and *GS2* are open.

8. A minimum value of one-megohm of insulation resistance is recommended before applying the high-potential test.

Note: Never apply high-potential tests unless a megger test first shows that the circuit is reasonably free from ground. Use only approved high-potential testing equipment.

9. In order to avoid excessive high-potential surges, always connect the high-potential test wires to the circuits before energizing the test wires.

10. To avoid any possibility of personal injury, always stay outside of and at least 10-feet from the locomotive while tests are being applied.

Application of Test Voltage. The normal operating voltage of the battery and low voltage control circuits is considered as 75-volts. This is 2.34-volts per cell of battery, which is approximately normal charging voltage. These circuits should not be given a high-potential test.

To apply high-potential tests to the main circuits and windings connect one high potential cable to any convenient point on the circuit to be tested and the other to the frame of the locomotive. Apply test voltage as specified below in Table 2:

TABLE 2. HIGH POTENTIAL VOLTAGES

Voltages	660 HP. Switcher & M. U. Switcher	1000 HP. Switcher & M. U. Switcher	1000 HP. Road-Switcher
Normal Operating Voltage	550	655	670
High-Potential Voltage for Testing Circuit	1000	1200	1200

Although the ICC requires the application of only 50-per cent above normal voltage to windings, it is permissible on this equipment to apply a high-potential test value of 75-per cent above normal operating voltage.

After Tests. 1. Remove grounding wire from wire 65C at GSS.

2. Remove jumpers across (or piece of metal between) contact tips of contactors S, SP1, and SP2.

3. On locomotives equipped with ammeters in the power circuits, reconnect the ammeter leads at the shunt.

Electric Rotating Machines. The following instructions apply to the traction generator, the traction motors and the exciter-

auxiliary generator set except as indicated. For additional maintenance see instructions under each machine.

Frequency of Inspection. A systematic schedule for inspection and overhaul should be established. Routine inspection should be made at every 3,000 miles and 75,000 miles, and general overhaul 150,000 to 200,000 miles or every 2 or 3 years, whichever occurs first.

Routine Inspection. Suggested for every 3,000 miles, or once a month where less than 3,000 miles a month is operated.

1. Clean all dirt from commutator cover and surrounding parts.

2. Remove commutator cover, taking care that no oil,, dust. or other foreign material falls into the machine. Blow out commutator chamber with clean dry compressed air, and clean by wiping with lintless cloth dipped in carbon tetrachloride to remove any oil or grease.

3. Inspect commutator. See that copper surface is free of copper beads and has a smooth and polished appearance. If commutator requires attention, refer to instructions under Commutator.

4. Wipe off string band. This surface must be free of oil and dirt and have a smooth glossy finish. Paint with Glyptal No. 1201 varnish if necessary.

5. See that brushholder mechanisms operate properly and that shunts and terminals are tight. Wipe the insulators clean and replace cracked or broken porcelains.

6. Examine brushes for surface condition and wear. Brushes should move freely in the holders, and not be stuck with dirt or other foreign substance. Raise and lower brushes in carbonways to release any dirt that may have accumulated. Care should be taken not to snap the springs as this may chip the brush.

7. Replace short or broken brushes with new ones of the proper grade.

8. Examine armature, field coils and connections for charred or broken insulation or other injuries. See that all connections are tight. When treatments are necessary, refer to Instructions Under Armature and Field Coils.

9. Replace commutator cover.

Note: Steps 10, 11, and 12 apply to the Traction Motors only.

10. Clean dirt away from oil filler pipe covers on axle caps. Check oil level which should be 1¾ in. minimum, 3½ in. maximum, measured on slant. Also see instructions on Axle Bearings under Traction Motor. See that all axle cap bolts are tight and properly locked.

11. Measure radial wear of motor axle bearing linings (1/16 in. wear limit), also end wear of the lining flanges (⅛ in. wear limit per lining flange).

12. Inspect gear lubrication. Be certain enough lubricant remains in case for operation until next inspection. See that bolts are tight and properly locked.

In addition to the regular routine inspection, the following should be observed.

Semi-Annual Inspection. This inspection is suggested for every 75,000 miles or semi-annually, whichever occurs first.

1. Axle Bearings: Inspect waste and correct packing if necessary. See Instructions on Axle Bearings under Traction Motor.

2. Generator Bearing: Add G-E ball-bearing grease to bearing. See Lubrication Chart.

3. Exciter-Auxiliary Generator Set (GMG-Set) Bearings: Add G-E ball-bearing grease to bearings. See Lubrication Chart.

Annual Inspection. 1. Traction Motor Armature Bearings: Add G-E ball-bearing grease to both commutator-end and pinion-end bearings. See Lubrication Chart.

Overhauling. The following operations are recommended for every 150,000 to 200,000 miles or every two to three years, whichever occurs first.

1. Clean dirt away around all openings, such as commutator covers; waste chamber covers and oil filler pipes on axle caps; and around armature bearing caps.

Note: Steps 2, 3, 4 and 5 apply to the Traction Motors only.

2. Measure radial wear (1/16 in. wear limit) and end play (⅛ in. wear limit per lining flange) of the axle bearings. Replace if more than the limits of wear recommended for these parts.

3. Remove old waste and oil from the axle caps and wash them out with kerosene or other petroleum cleaner.

4. Remove gear case.

5. Dismount the motor and remove the pinion with a pinion puller.

6. Remove the armature. (See Disassembly Procedure under each machine.) Blow out dust and dirt with clean dry compressed air. Recondition per detailed Instructions under Armature and Commutator.

7. Examine bearing housings to make sure grease leaks have not developed. Remove armature bearings and clean and inspect them in accordance with detailed Instructions under Lubrication.

8. Blow out with dry compressed air and clean the interior of the machine by wiping with lintless cloth dipped in carbon tetrachloride or equivalent, to remove any oil or grease.

9. If the field coils and connections are tight and in good condition give them two coats of G-E No. 1201 Glyptal insulating varnish. If necessary to remove the coils, proceed per detailed instructions under each machine.

10. See that the brushholder mechanisms operate properly, that shunts and terminals are tight, and that insulators are clean and free from cracks, also see that carbonways are not rough or worn. Check spring tension. See Maintenance Data under each machine.

11. See that pole piece bolts are tight and properly locked.

12. Fill countersinks around upper pole piece bolt heads with G-E No. 837 compound to exclude water.

13. Replace wearing plate on traction motor suspension nose if badly worn.

14. Reassemble armature bearings and housings on armature shaft. See instructions under each machine.

15. Reassemble the armature in the machine.

16. Check carefully that no foreign matter remains in the machine and that there are no loose brushes or other obstructions on the commutator.

17. Check connections with connection diagram.

18. On traction motors, remount the pinion. See Instructions Under Traction Motor.

19. Put in new brushes if necessary.

20. Clean and repaint gear cases. See Traction Motor for instructions.

21. Remount the machine.

22. See that all nuts and bolts are tight and properly locked; that covers are fastened into place and that cables are secured.

23. Traction motor axle caps should be packed with new waste and filled with oil. See Traction Motor for instructions.

24. Fill traction motor gear case with sufficient lubricant of the proper quality.

Armatures. Armature should be closely inspected for the condition of bands, wedges, coils, insulation, general assembly and the commutators.

Armature bands and core wedges should be tight and secure. Solder on the bands should be intact. If solder has thrown off, the cause should be determined and corrected and bands replaced.

The coil insulation should be clean and free from blisters, flakes or cracked insulating varnish surface. When the condition of the insulating varnish on the armatures is such that treatment is necessary, the following should be observed.

1. Wipe clean with cloth dipped in carbon tetrachloride or equivalent.

2. Heat the armature to 100 C. (212 F.).

3. Dip hot in Glyptal No. 1201 varnish, specific gravity 1.15 to 1.18 at 30 C.

4. Thoroughly drain excess accumulation of varnish.

5. Bake for 24 hours at an even temperature of 120 to 125 C. (248 to 257 F.).

Measure the insulation resistance while the armature is hot. Armature should be baked until the insulation resistance is at least 1 megohm.

If it becomes necessary to remove any of the armature coils, due to grounds, short circuits, or other damage, it is recommended that the complete armature be sent to the nearest service shop for repairs or rewinding.

The armature receives a dynamic balance at the factory. It is essential not to disturb the balance in any way. Be sure to check the balance after doing any work that may affect it.

Commutators. The commutator should present a smooth surface free from pitting. If it has become pitted or damaged from any cause, it should be stoned or turned. A stone of proper curvature to fit the commutator surface and having a span of approximately 30 degrees should be used. When stoning the commutator, extreme care should be taken to keep the copper dust from the windings. After stoning, check the brush surface for roundness and for concentricity with inner bearing race. The machine should be carefully blown out with dry compressed air.

If the commutator is badly worn or burned, the armature should be placed in a lathe and the commutator turned enough to give a uniform surface. Before turning the commutator, a suitable head covering should be placed over the end windings to prevent the chips working into the armature. While turning, the peripheral speed of the commutator surface should be about 300-ft. per minute. Remove the sharp corners from the ends of the commutator segments with a file.

If the commutator has been turned, the side mica should be grooved to the depth shown in Table 3.

TABLE 3. COMMUTATOR GROOVING DATA

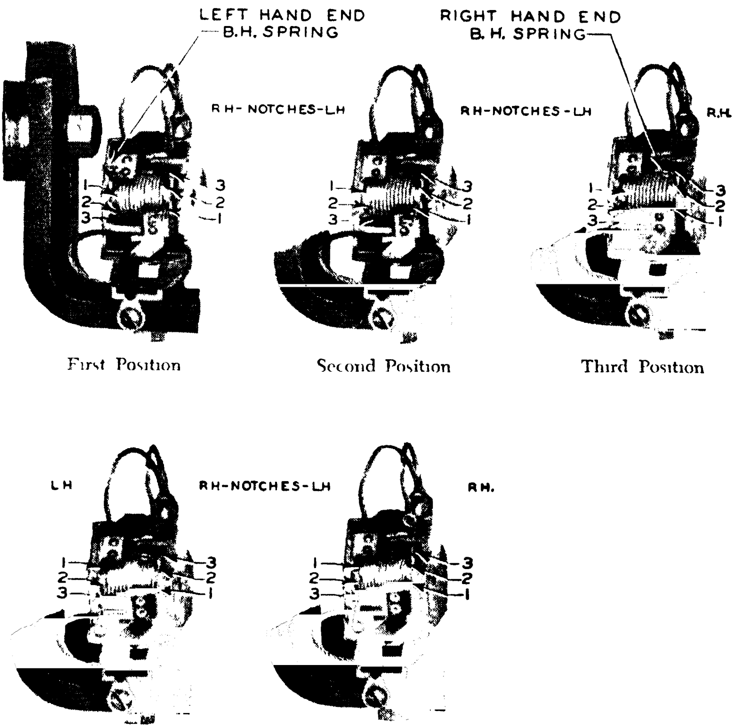
Apparatus	Grooving Depth	Side Mica Thickness
Traction Generator	3/64-in.	0.045-in
Traction Motor	5/64-in.	0.045-in.
GMG Set	3/64-in.	0.030-in.

Special saws are available for this purpose. Do not cut the slots too wide. The sharp edges of the bars should be removed with a hand scraper or a knife. Do not bevel the edges of the segments. Remove all mica fins and inspect to see that no copper chips remain. Final polishing with a fine grade of sandpaper is recommended. Polishing must be skillfully done in order to maintain a cylindrical surface.

Do not apply lubricant to the commutator as it is detrimental to operation. If the commutator is not kept clean and free from grease and oil, carbon dust will collect in the grooves between the segments, and will tend to cause a short-circuit.

SETTINGS OF BRUSHHOLDER SPRING ENDS

Spring End Positions	Notches	
	Left Hand	Right Hand
First	1	1
Second	2	1
Third	2	2
Fourth	3	2
Fifth	3	3



First Position Second Position Third Position

Fourth Position Fifth Position

Fig. 1. Spring End Settings for Adjustable Brushholder Springs for Traction Generator

Brushes and Brushholders. When replacing brushes use the same grade of brush or a manufacturer's recommended replacement. Especially is this true when only a partial replacement is made

TABLE 4. BRUSHHOLDER CLEARANCES

Apparatus	Clearance
Traction Generator	1/8-in.
Traction Motor	1/16-in. to 3/32-in.
Exciter-Aux. Generator Set	1/16-in. to 3/32-in.

as two widely different kinds of brushes on the same machine may be detrimental to its successful operation.

When new brushes are put in, they should be fitted to the commutator by sandpapering. In fitting brushes, a piece of sandpaper is inserted under the brush and drawn in the direction of rotation; lift the brush when moving the paper back, and keep the paper close to the commutator to avoid rounding the edges of the brush.

When assembling a full set of brushes on the generator, they should be fitted to the commutator surface. On the other machines, fitting is helpful but not absolutely necessary.

Maintain proper clearance (as shown in Table 4) between the bottom of brushholder and the commutator. The support is arranged in such a way that the brushholders may be moved toward the commutator surface as the commutator wears or is turned, so as to maintain the clearance between the face of brushholders and commutator. Brushholders should be kept rigidly bolted in place.

The shunts on the carbon brushes should be arranged so as to clear the commutator riser on the armature and the window in the body for the finger. See that the shunts and terminals are tight.

Proper brush pressure should be maintained as unequal brush pressure will cause unequal current distribution in the brushes. For brush pressure values refer to Maintenance Data under each machine. The brush pressures on the GMG set and the traction motors were set at the factory and should not require further adjustment unless repairs are made.

The brush pressures on the traction generator should be checked periodically. If they do not agree with those shown under Traction Generator Maintenance Data, Fig. 1, the brushholder spring ends should be set in the notches indicated in Table 5.

TABLE 5. BRUSHHOLDER SPRING SETTING FOR TRACTION GENERATORS

Generator	Brush Condition	Position of Spring Ends	Notches Left	Notches Right
GT-552	New	2	2	1
	½ worn	3	2	2
GT-553	New	4	3	2
	½ worn	5	3	3

Lubrication. *Anti-Friction Bearings.* These bearings are grease lubricated. Bearing grease recommended by the manufacturer should be used.

The grease fittings should be examined regularly to see that they are not damaged so as to allow dirt to enter the bearings. Before greasing, the fitting should be wiped clean so as not to force dirt into the bearings with the grease.

The amount of lubrication depends largely on the service requirements. Grease should be added periodically but not excessively as it will work out of the housing and be thrown off to the detriment of the unit when it gets on brushes, commutators, and windings, and clogs ventilating passages.

As conditions dictate, bearing assemblies should be taken apart and thoroughly cleaned with kerosene or other petroleum cleaner, for the purpose of removing the accumulation of old and hardened grease from bearings, housings, and grease passages.

The bearings should be given a visual inspection for defective balls or rollers and loose rivets or worn cages; in addition they should be checked for defects by rotating in the hand and feeling for grit or binding, and also by spinning and listening for noise. When the bearing condition is questionable, install a new bearing and have the doubtful bearing reconditioned or destroyed.

Immediately after bearings have been cleaned in the solvent, they should be further washed in a light mineral lubricating oil of SAE-10 grade heated to 90C. (194 F.). This is to prevent corrosion of the highly polished surfaces.

When the bearing compartment is clean and dry, repack with fresh grease. When reassembling, some grease should be packed into the bearing itself as well as on both sides of it. Refer to Main-

tenance Data under each machine for the grease capacity of the bearing assemblies. The total amount of grease should not exceed that recommended for the initial filling. An excessive amount will cause the bearing to run hot and will throw out and work into the machine.

It is recommended that a regular greasing schedule be established after experimenting to determine the frequency and the amount of lubrication required for the particular service that this equipment is to perform.

In general, experience with G-E ball bearing grease has shown that the bearings need only have grease added at infrequent intervals as indicated on the Lubrication Chart.

Motor Axle Bearings. See Instructions Under Traction Motor.

Field Coils. When field coils are to be removed, provisions should be made to keep each pole, coil, accompanying shims and bolts together. Upon reassembling, they should be replaced in their original position.

The condition of the insulating varnish surface of the field coil should be examined and when necessary the following treatment should be observed.

1. Wipe clean with cloth dipped in carbon tetrachloride or equivalent.
2. Paint or preferably dip hot in Glyptal No. 1201 varnish.
3. Drain thoroughly.
4. Bake 6 hours at 120 to 125 C. (248-257 F.).

After coils are reassembled, care should be taken that the cables are properly reconnected. Refer to connection diagram and carefully check the coil polarity. Contact surfaces should be clean, and the bolts drawn up tightly. Guard against loose connections at all times.

Locating Trouble. *Armature Overheating.* Armature heating may result from any one of the following causes:

1. Overloading or inadequate ventilation.
2. A partial short-circuit of two coils, heating the two coils affected.
3. Short circuits or grounds in the armature winding or commutator.

4. Bad commutation, with consequent large circulating currents in the armature coils undergoing commutation.

5. General heating of the armature may be caused by: (a) Unequal air gap; (b) Reversed field coil; (c) Short-circuited or grounded field coil.

Field Coils Overheating. Overheating of field coils may result from the following causes:

1. Partial short-circuit of one or more coils.
2. Faulty spools, or improper connections.

Check the connections of the field coils with the connection diagram for each machine. Check for reversed field coil by exciting the fields from some source (battery, etc.), and holding two iron rods against the adjacent pole tips all the way around; the free ends of the rods should attract each other. A faulty spool may be detected by exciting the fields from some source and taking the voltage drop across each spool separately; a variation of over 10 per cent in the drop indicates faulty spool.

It should be noted that the main generator and the exciter has more than one winding on each pole, and care should be taken to see that correct terminals are used; consult the cable connections drawings.

Commutator Overheating. Excessive temperature on the commutator is generally caused by the following:

1. Heavy overload for prolonged period.
2. Sparking at the brushes.
3. Improper brush pressure.
4. Poor condition of the commutator. A blackened or rough surface increases the brush friction and the contact drop, both of which cause increased temperature.

Contact Heating. Bolted contacts may heat if the contact surfaces are not clean, smooth, and bolted together with sufficient pressure. See that the contacts of connecting strips are tight.

Poor Commutation. Sparking at the brushes may be due to any one of the following causes:

1. Excessive overload.
2. Brushes may not have proper pressure, or the pressure may not be the same on all brushes.

3. Brushes may bind in the holders.
4. Brushes may have reached their limit of wear.
5. Brushes may be burned on the ends.
6. The commutator may be dirty, oily, rough, or worn out.
7. A commutator bar or bars may be loose or may project above the others.
8. High mica.
9. Grounded or short-circuited armature coils.
10. Loose connection between armature lead and commutator bar.
11. Flat spot on the commutator.
12. Commutator out of true.
13. Armature badly out of balance.

TRACTION GENERATOR

Function. The traction generator changes the mechanical power developed by the Diesel engine into electrical power for driving the traction motors. It also serves as a starting motor for cranking the engine when properly connected to a current supply.

Description. This generator is designed especially for traction purposes. The armature is direct-connected to an internal combustion engine, and rotates in a CCW direction, looking at its commutator end. The generator frame is joined with the engine structure by means of a bolting flange.

A framehead located at the commutator end of the generator frame encloses the single main generator self-aligning bearing which supports the commutator end of the armature, the other end being supported through the rigid coupling by the main engine bearing. There is sufficient clearance in the generator bearing for horizontal movement of the armature (end play) so that the end thrust is taken by the engine bearing.

The engine end of the armature carries the fan which draws air for cooling purposes through the longitudinal armature ventilating ducts as well as over the armature and field surfaces. The air flow is from the commutator end, where the cooling air is drawn in, toward the engine end, where the heated air is discharged through the fan. It is essential that sufficient amount of cool clean

air be provided, and provision made to prevent re-circulation of the exhaust air. Adequate ventilation will not be obtained unless the fan discharges against pressure no greater than intake air pressure.

Separate main field excitation is supplied through the split pole exciter end of the Type GMG set, which governs the output characteristic of the generator.

A starting field is built in with the main field to supply excitation for engine cranking.

The main armature shaft is extended through the commutator end bearing for belt-driving the exciter-auxiliary generator set and the traction motor blower, and for direct coupling to the air compresser.

Disassembling Parts for Repair. Refer to Longitudinal Section Fig. 2. The special main generator bearing puller is furnished with the generator to facilitate disassembling of parts.

Complete Generator. To remove the complete generator out of the locomotive:

1. Place fibre or pressed board shims into the air gap so the armature will not drop down on the pole pieces.
2. Disconnect all cables from the set.
3. Uncouple the armature.
4. Disconnect the generator frame from the engine bell-housing.
5. Remove the complete generator.

Armature. To remove the armature:

1. Remove fan. **Note:** Place suitable marks on the fan so that when reassembled the balance weight will be in its original angular position with respect to the engine crankshaft.
2. Disconnect the main generator bus ring from the commutating field.
3. Raise the main generator brushes and wrap heavy paper around the commutator surface to protect it.
4. Remove pulley with suitable puller.
5. A long pipe extension should be slipped over the engine end stub shaft.
6. If only one crane hook is available a heavy rope sling may be used, wrapping one end around the commutator end shaft extension and the other end on the pipe extension.

7. The weight of the armature assembly should be taken up by the crane before removing air gap blocking or framehead bolts 24.

8. The armature assembly consisting of main generator arma-

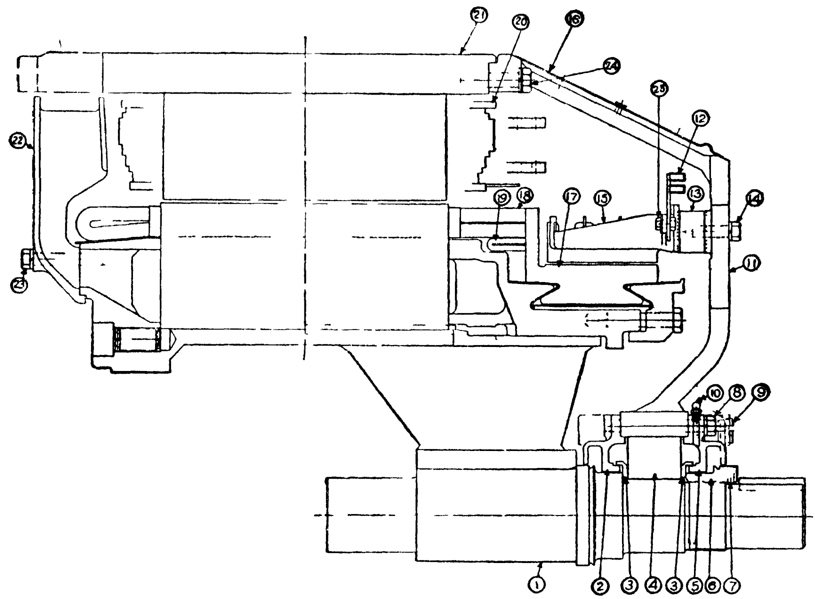


Fig. 2. Longitudinal Section Traction Generator, Types GT-552 and GT-553

1 Shaft
2 Inner Bearing Cap
3 Flingers
4 Bearing
5 Outer Bearing Cap
6 Bearing Nut
7 Set Screw
8 Cap Bolt
9 Inspection Plug
10 Grease Fitting
11 Frame Head
12 Brush Holder Bus Rings
13 Brush Holder Support
14 Brush Holder Support Bolt
15 Brush Holder
16 Frame Cover
17 Commutator
18 Armature Windings
19 Equalizer
20 Field Coils
21 Magnet Frame
22 Fan
23 Fan Bolt
24 Frame Head Bolt
25 Bus Ring Connection Bolt

ture and framehead should next be removed carefully from main frame assembly.

9. The armature assembly should be supported on curved wood blocks, under core portion of main armature, and under framehead.

Generator Bearing. To remove the bearings:

1. Loosen the set screws 7.

2. Remove bearing nut 6.

3. Remove bearing cap bolts 8.
4. Slip off outer bearing cap 5.
5. Remove framehead 11.
6. Screw puller studs into inner bearing cap 2.
7. Place puller plate against shaft. Studs will now project through holes in plate.

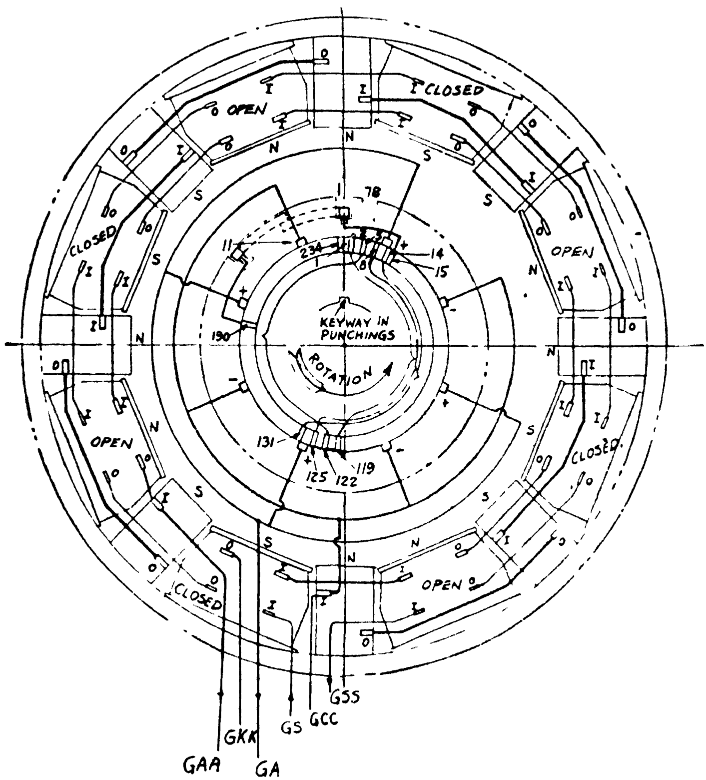


Fig. 3. Connection Diagram, Traction Generator, Type GT-552-A Facing Commutator End

8. Apply nuts to studs.

9. Tighten nuts to draw plate against shaft, until bearing is pulled. (Bearing 4, inner and outer flingers 3, and inner bearing cap 2 are pulled simultaneously).

To replace the bearing:

The order of reassembling the main generator bearing is as follows:

1. Inside bearing cap 2.

2. Inside flinger 3.

3. Bearing 4. It should be either pressed on, (approx. one ton pressure), or shrunk on. If it is shrunk on, it should be heated, with the framehead, to 110 C. and then held against the flinger

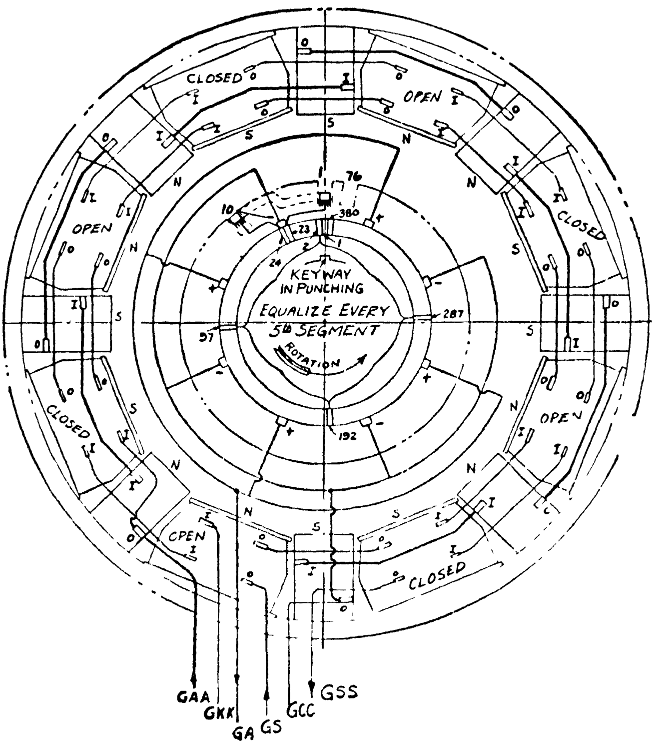


Fig. 4. Connection Diagram, Traction Generator, Type GT-553-C Facing Commutator End

while it cools. Care must be used not to exceed this temperature as the bearing temper may be affected. A properly controlled oven is recommended for heating.

4. Pack the bearing with grease. Refer to Lubrication Instructions.

5. Outside flinger 3.

6. Outside bearing cap 5.

7. Bearing nut 6, which should be locked in place firmly using set screws 7. Prick punch set screws.

Field Coils. To remove a field coil without removing the generator from the engine.

1. The three nearest brushholders must be removed.
2. All brushholder bus ring connections disconnected.

TABLE 6. GENERATOR COILS, TYPE GT-552-A

Coils	Cat. No.
Armature, 1 Turn	4744882G1
Armature Equalizer	4729035G1
Exciting Field, Open	4748252G1
Exciting Field, Closed	4748252G2
Commutating Field	4744875G1

3. Bus rings moved into a position to provide room so that an exciting pole and coil may be pulled out endwise between arms on the framehead 11.
4. To remove a commutating pole and coil an exciting pole and coil must first be removed.
5. The exciting coil can easily be slipped off the pole. The commutating coil is permanently assembled on the pole and cannot be readily disassembled.
6. If the main generator has been removed from the engine, the field coils can be removed through the back end of the frame without disturbing brushholders and brushholder bus rings, providing the fan has been taken off.
7. New lockwashers should be used with each reassembly.

TABLE 7. GENERATOR COILS, TYPE GT-553-A

Coils	Cat. No.
Armature, 1 Turn	4742637G1
Armature Equalizer	4729398G1
Exciting Field, Open	4748246G1
Exciting Field, Closed	4748246G2
Commutating Field	4742650G1

Reassembly of Generator. In general, reassembly procedure is the reverse of the suggested disassembly procedure outlined above. Care should be taken in assembling bearing parts to prevent scoring the engaging surfaces of tight fitting parts. Make sure that the armature fan is reassembled so that the balance weight is in its original position with respect to the engine crankshaft.

Lining Up the Generator with the Engine. The proper operation of the set requires that the generator shaft be in line with the

engine shaft, and that the air gaps be equally divided. On some generators the armature may be jacked into line by means of four jacking bolts screwed into holes in the bottom of the generator frame. Refer to Fig. 5 and Fig. 6 for proper method.

The air gap must be uniform within plus or minus 10 per cent from average under each main pole as well as under each commu-

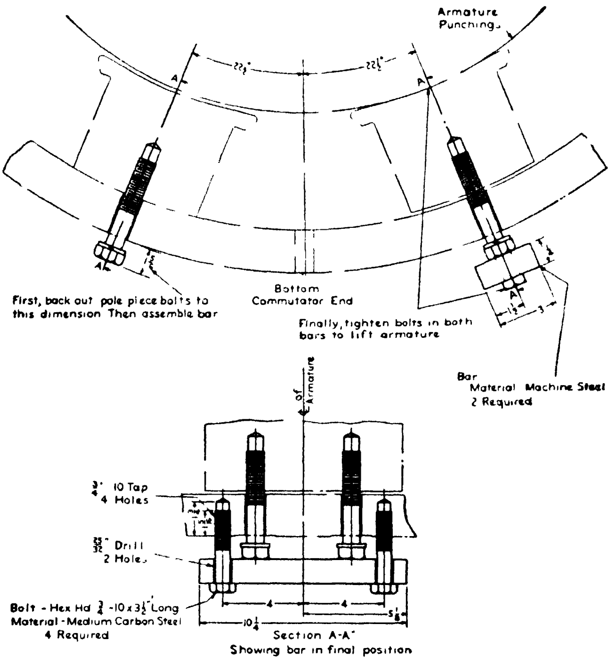


Fig. 5 Armature Jacking Arrangement, Generator Type GT-532

tating pole, and also in front and back. It is recommended that revolving gap be taken, that is, select a point on the armature core surface (laminations), revolving the armature, measure successively the gap between this point and the poles. Air gap should always be measured under the center of the pole. Eccentricity at the coupling end should be held to a minimum as this directly affects balance, brush and bearing wear.

After the armature is coupled to the engine, care should be taken to locate the frame so as to have the bearing centrally aligned in the end play direction to avoid excess thrust load in either

direction. A determination of the positions can be made by shifting the bearing to its two extreme end positions and then setting finally midway between these two extremes.

Testing After Repairs. Generators that have been repaired after running in service, must not be given over one-half of the voltage specified for the high potential test for a new machine. For

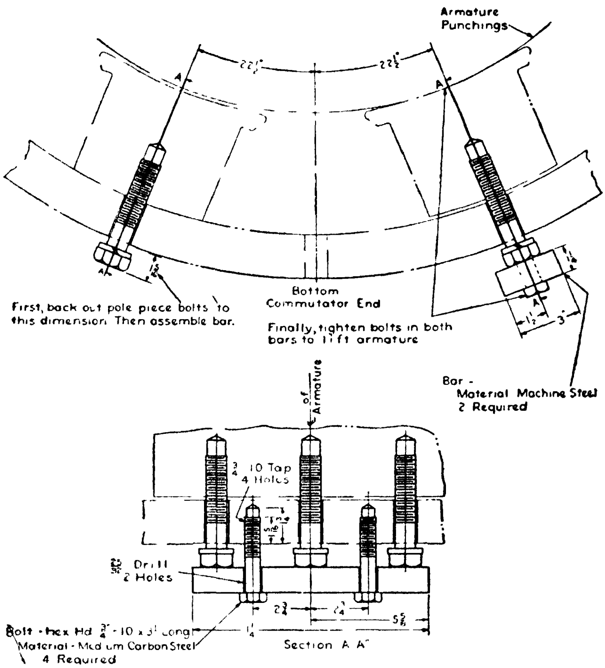


Fig. 6. Armature Jacking Arrangement, Generator Type GT-553

main generator armature, commutating field and starting field, use not over 1200-volts; for main generator shunt field not over 550-volts. See Instructions on I. C. C. High Potential Tests.

TABLE 8. MAINTENANCE DATA TRACTION GENERATORS

Type GT-552-A3 Generator (Model 5GT552A3)
Type GT-552-A4 Generator (Model 5GT552A4)

Classification—8-pole, commutating-pole type, d-c generator
Nominal Rating—660 hp. at 740 r.p.m.
Resistance at 25 C

Shunt Field	0.070 ohm
Commutating Field	0.00413 ohm
Starting Field	0.00385 ohm

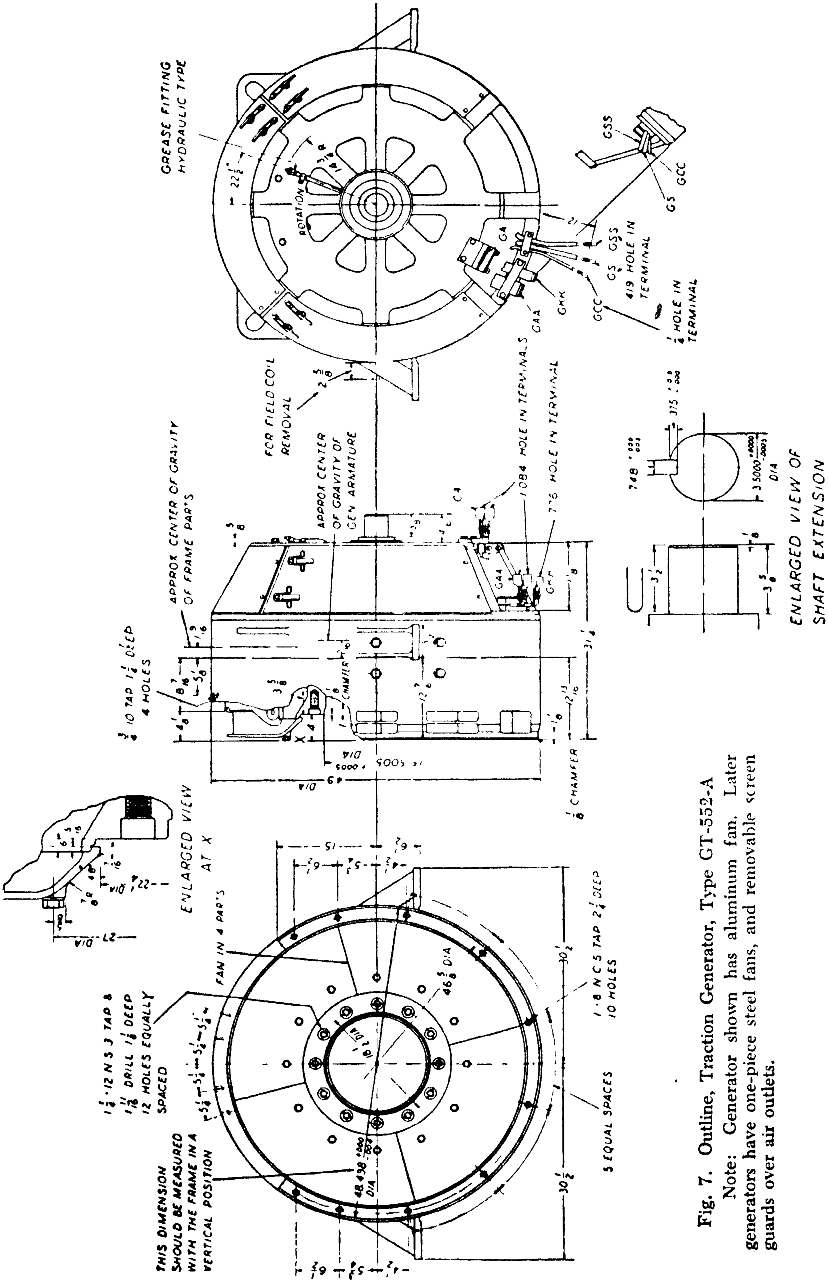


Fig. 7. Outline, Traction Generator, Type GT-552-A

Note: Generator shown has aluminum fan. Later generators have one-piece steel fans, and removable screen guards over air outlets.

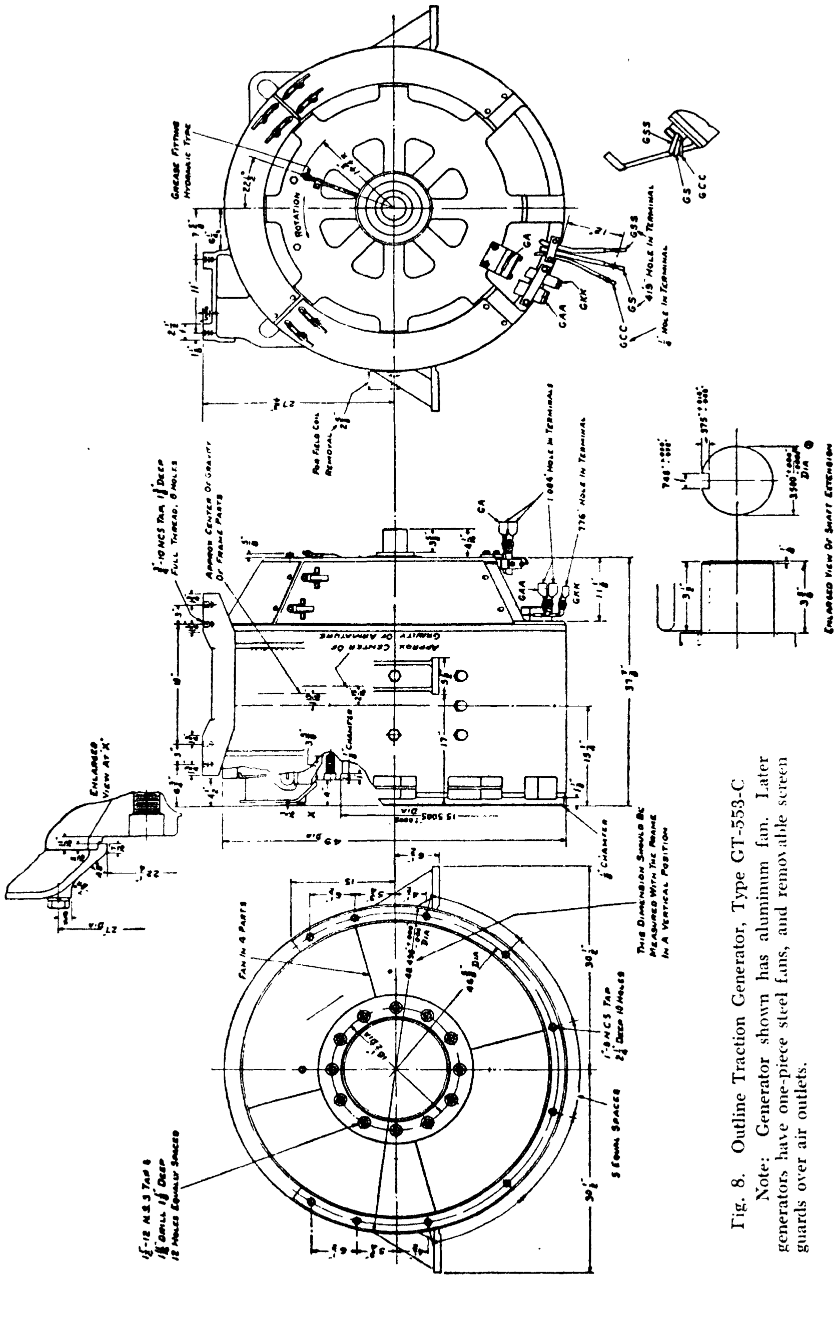


Fig. 8. Outline Traction Generator, Type GT-553-C

Note: Generator shown has aluminum fan. Later generators have one-piece steel fans, and removable screen guards over air outlets.

Brush Data

Tandem brushes, one 10° trailing; other 30° stubbing

- Pressure .... (Nominal) 45 oz. per brush
- Size .... ½-in. by 1½-in. by 2¼-in.
- Grade GE-377

Average Air Gap

- Exciting Field .... 0.171-in.
- Commutating Field .... 0.343-in.

Commutator Side Mica

- Thickness .... 0.045-in.
- Grooving Depth .... 3/64-in.

Bearing Grease Capacity (⅔ Full) .... 17 oz.

	GT-552-A3	†GT-552-A4
Weight of Entire Unit	6942-lb.	7013-lb.
Weight of Bare Armature and Fan	3010-lb.	3081-lb.

Drawings

- Longitudinal .... Fig. 2
- Connection Diagram .... Fig. 3
- Outline .... Fig. 7

†Has steel fan.

TABLE 9. MAINTENANCE DATA TRACTION GENERATORS

Type GT-553-C2 Generator (Model 5GT553C2)
Type GT-553-C3 Generator (Model 5GT553C3)

Classification—8-pole, commutating-pole type, d-c generator

Nominal Rating—1000 hp. at 740 r.p.m.

Resistance at 25 C

- Shunt Field .... 0.705 ohm
- Commutating Field .... 0.0033 ohm
- Starting Field .... 0.0037 ohm

Brush Data

Tandem brushes; one 10° trailing; other 30° stubbing

- Pressure .... (Nominal) 39 oz. per brush
- Size .... ⅜-in. by 1½-in. by 2¼-in.
- Grade GE-377

Average Air Gap

- Exciting Field .... 0.170-in.
- Commutating Field .... 0.351-in.

Commutator Side Mica

- Thickness .... 0.045-in.
- Grooving Depth .... 3/64-in.

Bearing Grease Capacity (⅔ Full) .... 17 oz.

	GT-553-C2	†GT-553-C3
Weight of Entire Unit	9225-lb.	9297-lb.
Weight of Bare Armature and Fan	3800-lb.	3881-lb.

Drawings
Longitudinal . . . . Fig. 2
Connection Diagram . . . . Fig. 4
Outline . . . . Fig. 8
†Has steel fan.

EXCITER-AUXILIARY GENERATOR SET

Function. The auxiliary generator end of the GMG set furnishes auxiliary power for the control circuits, battery charging,

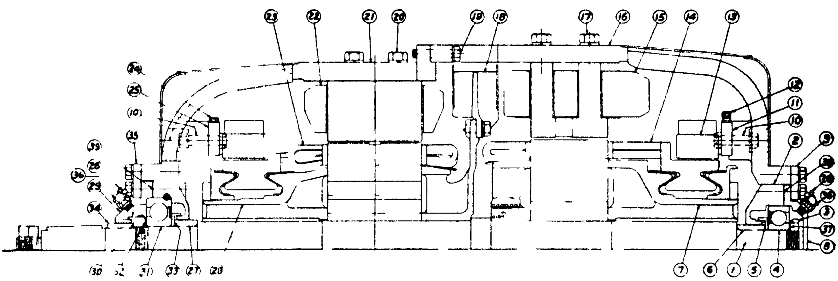


Fig 9 Longitudinal Section, Exciter-Auxiliary Generator Set Types GMG-139-A and GMG-139-B

1 Shaft
2 Bearing Housing (Exc)
3 Bearing Nut (Exc)
4 Bearing (Exc)
5 Flinger Inner (Exc)
6 Spacing Collar (Exc)
7 Commutator (Exc)
8 Bearing Cap
9 End Plate (Exc.)
10 Brush Holder Support Bolt
11 Brush Holder Support (Exc)
12 Brush Holder Bus Rings (Exc)
13 Brush Holder
14 Armature Winding (Exc)
15 Field Coils (Exc)
16 Magnet Frame (Exc)
17 Pole Piece Bolts (Exc)
18 Fan
19 Joint Bolts
20 Pole Piece Bolts
21 Magnet Frame (Aux Gen)
22 Field Coils (Aux Gen)
23 Armature Winding (Aux. Gen)
24 Brush Holder Bus Rings (Aux Gen)
25 Brush Holder Support (Aux Gen)
26 Grease Fitting
27 Spacing Collar (Aux. Gen)
28 Commutator (Aux Gen)
29 Bearing Cap (Aux Gen)
30 Bearing Nut (Aux. Gen)
31 Bearing (Aux Gen)
32 Lockwasher
33 Flinger Inner (Aux. Gen)
34 Collar (Aux Gen)
35 End Plate (Aux Gen)
36 Overflow Fitting
37 Lockwasher (Exc)
38 Gasket (Exc)
39 Gasket (Aux Gen)

exciter shunt field excitation, miscellaneous power and lights. Steady voltage is maintained by the voltage control relay.

The exciter end of the machine furnishes excitation for the traction generator. It is tested with and adjusted under test with the generator whose serial number is stamped on its nameplate. Do not use it with any other generator or correct operating results will not be obtained.

Description. The Type GMG exciter-auxiliary generator set is essentially two separate electric machines, an auxiliary generator and an exciter, mechanically built into the same frame assembly with two armatures mounted on the one shaft. The unit is belt driven through a pulley mounted on the auxiliary generator end shaft extension. The unit rotates in a clockwise direction, looking at the shaft extension end.

The unit is cooled by air drawn into the machine by a fan. It is, therefore, essential that sufficient amount of cool clean air be

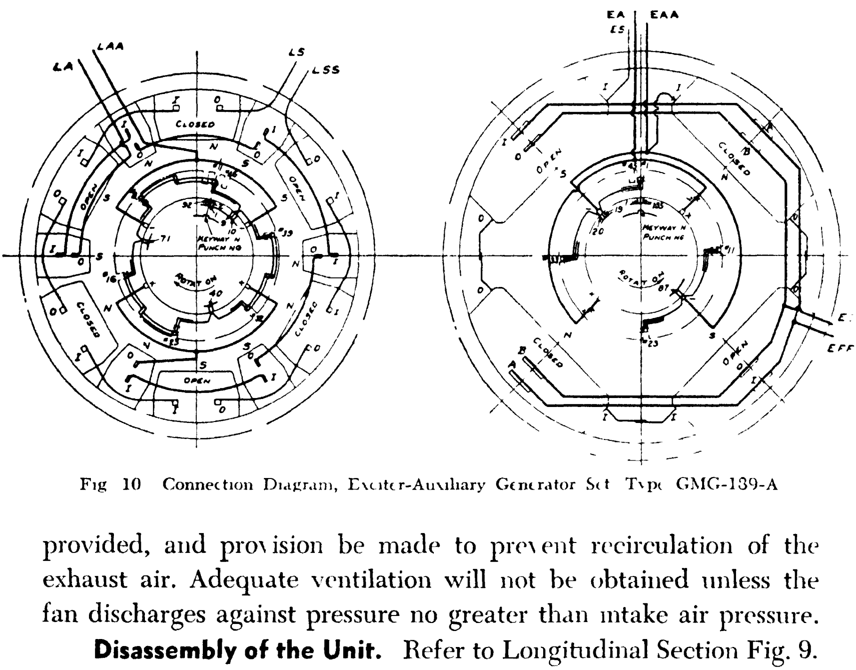


Fig 10 Connection Diagram, Exciter-Auxiliary Generator Set Type GMG-139-A

provided, and provision be made to prevent recirculation of the exhaust air. Adequate ventilation will not be obtained unless the fan discharges against pressure no greater than intake air pressure.

Disassembly of the Unit. Refer to Longitudinal Section Fig. 9.

Armatures. To remove the armatures:

1. Lift the brushes from both commutators and wrap a piece of paper around each commutator to protect it.
2. Take off the pulley.
3. Remove the grease and overflow fittings 26 and 36.
4. Take out the joint bolts 19.
5. Place wooden block under auxiliary generator frame 21.
6. Take out the inner row of bolts for end plate 9.

7. Screw ejection bolts in tapped holes provided in end plate 9. This will remove magnet frame 16, leaving the complete armature assembled in frame 21.

8. Support armatures with a rope sling around the fan.

9. In a similar manner, take out the inner row of bolts for end plate 35 and apply the ejection bolts in the tapped holes provided in the end plate, thus removing the frame 21, from the armature.

TABLE 10. COILS FOR GMG-139-A MOTOR GENERATOR SETS

Type	AUX GENERATOR			
	Turns	Armature Coil	Exciting Field	Commutating Field
GMG-139A1	2	Cat. 4742734G1	Open Cat. 4748238G1 Closed Cat. 4748238G2	Cat 4742740G1
GMG-139A2	2	Cat 4742734G1	Open Cat. 4748238G1 Closed Cat 4748238G2	Cat. 4742740G1
GMG-139A3	2	Cat 4742734G1	Open Cat. 4748238G1 Closed Cat. 4748238G2	Cat. 4742740G1

Type	EXCITER		
	Turns	Armature Coil	Exciting Field
GMG-139A1	1	Cat. 4748231G1	Open Cat. 6751109G3 Closed Cat. 6751109G4
GMG-139A2	1	Cat 4748231G1	Open Cat. 6751109G1 Closed Cat. 6751109G2
GMG-139A3	1	Cat. 4748231G1	Open Cat. 6751109G5 Closed Cat. 6751109G6

Bearings: To remove the bearings:

1. Remove countersunk head screws which hold the bearing cap 8 to the bearing housing 2. This will permit disassembly of bearing cap 8.

2. Remove bearing nut 3.

3. Bearing 4, inner flinger 5, and bearing housing 2 can be removed simultaneously by using a suitable puller.

4. After removing the collar 34, the pulley end bearing can be removed similarly to the exciter end bearing.

Care should be exercised in the handling of the parts so as not to damage them, particularly the windings and commutators.

Fan. The fan is of one-piece construction bolted to a machined flange. By removing the bolts the fan can be slipped off over the exciter armature.

Field Coils. To remove a field coil:

1. Disconnect the cables.

2. Remove the bolts which hold the pole to the frame.

3. Remove the pole and coil through the end of the frame.

4. The field coil can readily be slipped off the pole.

Where field coil pole piece bolts have been removed, new lockwashers should be provided upon reassembling.

Reassembly. In general, reassembly procedure is the reverse of the suggested disassembly procedure outlined above. Parts having a shrink fit should be heated in an oven to facilitate assembly.

Testing After Repairs. Exciter-auxiliary generator sets that have been repaired after running in service, must not be given over one-half the voltage specified for the high potential test of a new machine. For the exciter differential field use not over 1200-volts; for all other parts of exciter and auxiliary generator use not over 600-volts. See Instructions I. C. C. High Potential Tests.

TABLE 11. MAINTENANCE DATA

Type GMG-139-A Exciter-Auxiliary Generator Set Model 5GMG139A

Classification

Auxiliary Generator—6-pole, commutating-pole type, d-c generator

Exciter—4-pole, non-commutating-pole type, d-c exciter

Nominal Rating (Auxiliary Generator) .... 5-kw.

Nominal Voltage .... 75 volts

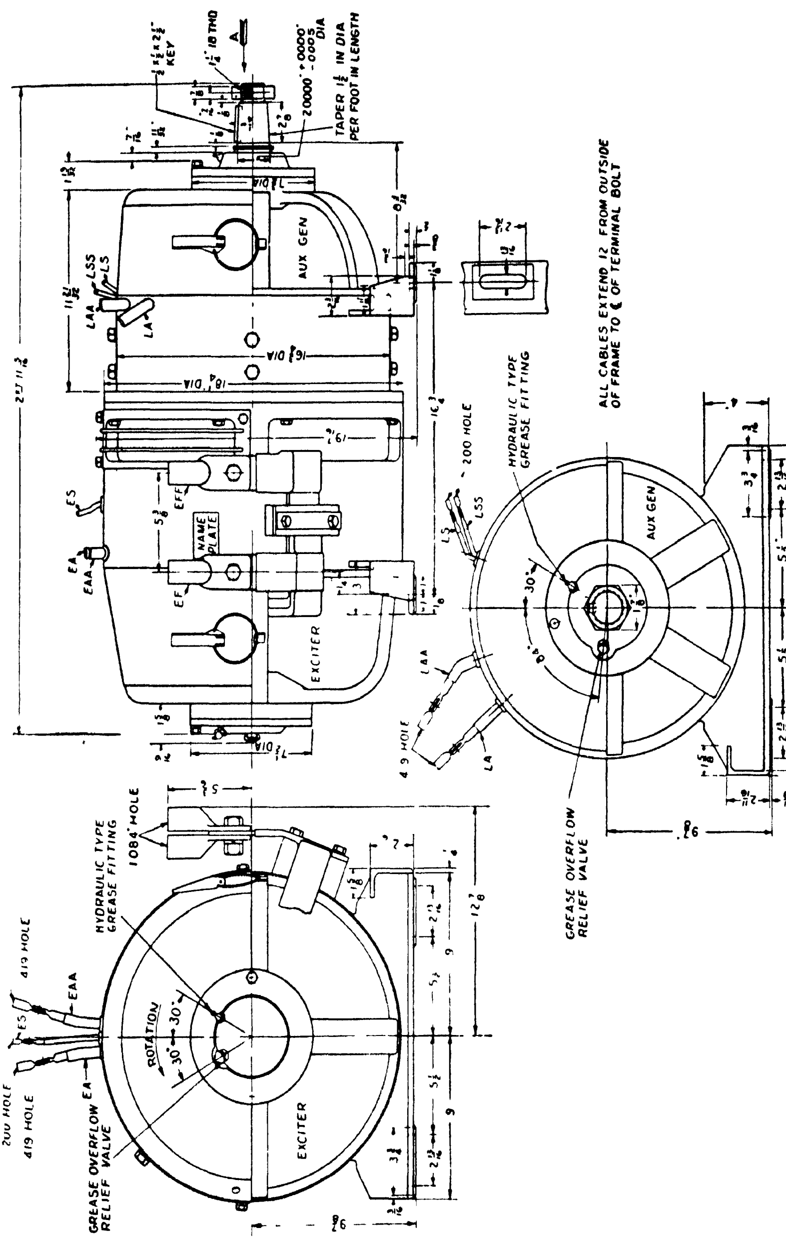


Fig. 11. Outline, Exciter-Auxiliary Generator Set, Type GMG-139-A

Resistance at 25 C
- Auxiliary Generator Shunt Field .... 10.78 ohms
- Auxiliary Generator Commutating Field .... 0.0267 ohm
- Exciter Shunt Field .... 3.74 ohms
- Exciter Differential Field
  - Form A1 .... 0.000196 ohm
  - Form A2 .... 0.000156 ohm
  - Form A3 .... 0.000123 ohm

Brush Data
- Pressure .... 46 to 52 oz. per brush
- Size .... ½ in. by 1¾ in. by 1¾ in.
- Grade GE-377

Commutator Side Mica
- Thickness .... 0.030-in.
- Grooving Depth .... 3/64-in.

Bearing Grease Capacity (⅔ Full)
- Shaft Extension End .... 2½ oz.
- End Opposite Extension .... 2¼ oz.

Weight of Set .... 800-lb.

Weight of Bare Armatures .... 310-lb.

Drawings
- Longitudinal .... Fig. 9
- Connection Diagram .... Fig. 10
- Outline .... Fig. 11

TRACTION MOTOR

Function. The traction motor takes electrical power from the generator and changes it into mechanical power to drive the locomotive.

Description. This motor is of the box frame type and is arranged for forced ventilation. The armature is supported at each end of the motor by anti-friction bearings carried in detachable frameheads. Single reduction gearing is enclosed in a split-type gear case.

The axle bearings are of the split-sleeve type, lubricated by means of oil and waste and have auxiliary oil wells for replenishing the oil supply and gauging its depth.

The motor has four main poles and four commutating poles. Four brushholders are accessible through the commutator covers.

Disassembly of Motor. Refer to Fig. 12. Before proceeding, make sure the oil and waste have been removed from the axle caps.

1. Unscrew pinion nut from end of shaft and pull the pinion from the shaft using a pinion puller. See Pinion instructions.

2. Remove carbon brushes.

3. Wrap heavy paper around commutator surface to protect it when armature is removed from the frame.

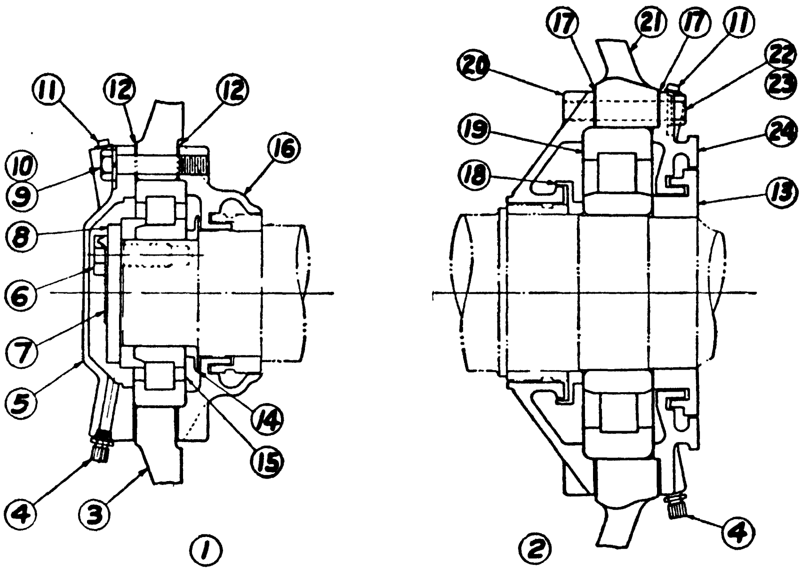


Fig. 12. Bearing Assembly, Traction Motor, Type GE-731

1 Assembly (Comm. End)	9 Bolt	17 Gasket
2 Assembly (Pinion End)	10 Lockwasher	18 Flinger
3 Frame Head	11 Pipe Plug	19 Roller Bearing
4 Lubricating Fitting	12 Gasket	20 Bearing Cap (Inner)
5 Bearing Cap (Outer)	13 Sleeve	21 Frame Head
6 Bolt	14 Flinger	22 Bolt
7 Washer	15 Roller Bearing	23 Lockwasher
8 Plate	16 Bearing Cap (Inner)	24 Bearing Cap (Outer)

4. Remove the eight bolts 9 holding inner and outer bearing caps to framehead on commutator end.

5. Remove outer cap.

6. Turn motor on end, with commutator end down, and level it so the armature can be raised vertically without injuring the bearings, commutator or brushholders.

7. Remove bolts holding pinion end framehead 21 to frame.

8. Screw hardened steel bolts into the threaded jack holes in the framehead.

9. To lift the armature, an eye bolt which fits the crane hook should be screwed over the threaded end of the armature shaft.

10. Screw three long straight studs in three of the holes in commutator end inner bearing cap 16. These long studs will guide the armature out of the frame so that the commutator will not strike the brushholders.

11. Remove bolts 6, washer 7 and plate 8 from the commutator end.

12. With the armature shaft vertical and the lifting ring in place, jack loose the pinion-end framehead. During this operation take care that the armature is properly levelled and that there is sufficient strain on the hoist cable to keep the armature weight from bearing on the framehead.

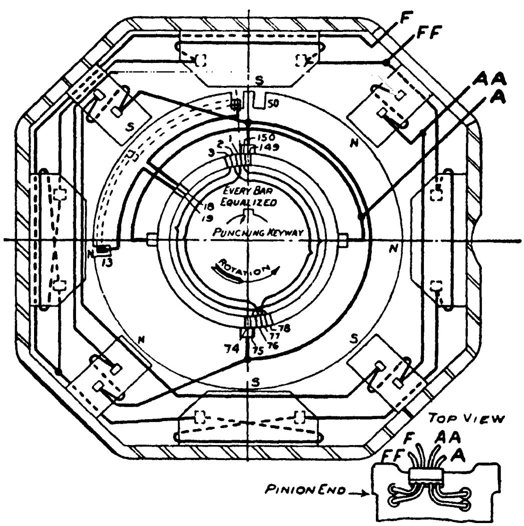


Fig. 13. Connection Diagram, Traction Motor Leads Are Shown on Axle Side

TABLE 12. MOTOR COILS GE-731-B2 AND GE-731-C2

Motor	Turns	Armature Coil	Exciting Field	Commutating Field
			Bottom and Susp. Side	
GE-731-B2			Cat. 6751106G1	
	1	Cat. 4748551G1	Axle Side	
GE-731-C2			Cat. 6751106G2	Cat. 6751105G1
		Cat. 4729679G1	Top Side	
		Equalizer	Cat. 6751106G3	

13. The thrust ring of the commutator end roller bearing must be caught to avoid damage when it drops off as the armature is lifted.

14. The armature together with the pinion-end bearing assembly and commutator end bearing inner race may then be lifted clear of the frame and placed on a bench or rack in a horizontal position.

Reassembly of Motor. Refer to Fig. 12. 1. Assemble flanges and coils on pole pieces. Bolt pole pieces into frame, drawing tight with coils hot. Fill countersinks around pole piece bolt heads with G-E No. 837 compound to exclude water.

2. Bolt brushholders in place. Fasten and insulate connections. Install cables. Assemble commutator end framehead with outer race and rollers.

3. Place frame in a vertical position with framehead face level, commutator end downward. Have ready an armature with pinion-end bearing assembly, less part 13, and commutator end bearing inner race in place. Screw eye-bolt over end of armature shaft. See Instructions covering armature bearing assembly given under Care of Armature Bearings.

4. Wrap heavy paper around commutator surface to protect it and lower armature into frame taking care not to strike the brushholders. Assemble studs into commutator end inner bearing cap to guide armature. Lower armature into frame.

5. Insert the pinion-end framehead bolts and tighten bolts to draw armature into place. Be extremely careful to pull down evenly on all bolts to prevent tipping the bearing assemblies and damaging the raceways.

6. Check the radial clearance between the commutator end bearing rolls and race with a feeler gauge. The assembled clearance should be 0.0025-in. minimum.

7. Assemble thrust ring on commutator end bearing. Assemble plate 8, washer 7 and bolts 6, but do not lock.

8. Place the motor in a horizontal position. Tighten framehead bolts.

9. Clamp an indicator to the commutator-end of the armature shaft with the plunger horizontal and pressing against the outer raceway of the bearing. Push the armature toward the commutator-

end to eliminate any end-play and rotate to see if the outer raceway is true.

If the outer raceway is out more than two thousandths of an inch (.002-in.) the bearing housing should be checked to see that all bolts are pulled up tight to the magnet frame and that there is no interference caused by burrs or dirt between the register fits of the bearing housing and magnet frame. This type of bearing is designed with small clearances and must, therefore, be properly lined up with respect to the armature shaft and housing in order to give satisfactory operation.

10. Force armature to commutator end. Tighten bolts and lock with 7.

11. Attach gasket 12. Be sure this gasket is correct thickness (0.021 in.).

12. See that commutator-end bearing has proper filling of grease, (10 oz. for bearing and housing), then attach bearing cap and draw bolts up tight.

13. Check armature end play (0.005 in. to 0.015 in. total).

14. Remove pinion end outer bearing cap 24 and check outer race of bearing with an indicator clamped to the shaft as was done on the commutator end. If the outer race runs out more than 0.003 in. check to see that all bolts are pulled up tight to the magnet frame, that there is no interference caused by burrs or dirt between the framehead and the fit on the magnet frame.

15. Check the radial clearance between the pinion-end bearing rolls and race with a feeler gauge. The assembled clearance should be 0.003 in. minimum.

16. Attach gasket 17.

17. See that bearing cap 24 has proper filling of grease, then assemble it and tighten bolts 22. Shrink labyrinth sleeve 13 in place. See detail instructions under Care of Armature Bearings.

18. Install carbon brushes. Use the grade recommended by the manufacturer. All brushes in the machine should be of the same grade.

19. Motor is now ready for pinion. See instructions for mounting pinions.

Care of Armature Bearings. When overhauling the motor,

after the outer races with rollers have been slipped off in accordance with instructions on disassembly, remove the old grease from bearing housings, flingers, and adjacent parts. Inspect the inner races, which need not be removed if in good condition.

Dissassembly of Commutator-End Bearings. Refer to Fig. 12. 1. The inner bearing race may be removed by applying a puller between the inner race and flinger 14.

2. Remove flinger 14 and inner bearing cap 16 by puller attached to threaded holes in inner bearing cap, 16.

Disassembly of Pinion-End Bearing. Refer to Fig. 12. 1. Remove the labyrinth sleeve 13. This sleeve contains 4 tapped holes for applying a puller.

2. Remove the bolts 22 and the bearing cap 24.

3. Slip framehead 21 together with outer race of bearing and rollers off of inner bearing race on shaft.

4. Remove inner bearing race by applying a puller to the inside face of race.

5. Remove flinger 18 and inner bearing cap 20 by puller attached to threaded holes in inner bearing cap 20.

Cleaning. 1. Immediately upon removing bearings, clean them with kerosene or other petroleum cleaner.

2. Do not allow them to lie around with old grease in them.

3. Clean bearing housings, flingers, and adjacent parts.

4. Immediately afterward, dip in light mineral oil (SAE 10 grade) heated to 90 C. (194 F.) and pack with fresh lubricant to avoid corrosion and wrap to keep clean.

Roller bearings should be cleaned and inspected each time the motor is overhauled.

1. Examine bearings for defective rollers, rotating each roller.
2. Inspect the cages for loose rivets and wear.
3. Inspect the inner race.
4. Protect from dirt the bearings that have been cleaned.
5. Do not take the bearing cages apart.

Assembly of Bearings. Refer to Fig. 12. The order of assembly is essentially the reverse of disassembly. Parts having a shrink fit should be heated in a bath of clean oil or in an oven to approximately 230 F. before mounting. The outer bearing races with rollers

and retainers are pressed into the frameheads before frameheads are assembled in frame. Care should be used to have the outer race of the bearing parallel with the bore of the framehead when pressing the bearing race into place. Gaskets 12 and 17 should have the correct thickness (0.021 in.).

Commutator-End Bearing Assembly. 1. Place inner bearing cap 16 and shrink on flinger 14.

2. Heat inner bearing race to prescribed temperature and shrink in place on shaft, holding inner race against the flinger on the shaft until cool.

3. Care should be exercised to keep the bearing free of foreign material.

Pinion-End Bearing Assembly. 1. Assemble inner bearing cap 20 and shrink flinger 18 on shaft.

2. Heat inner bearing race to prescribed temperature and shrink in place on shaft, holding inner race tightly against flinger on shaft until cool.

3. Framehead with rollers should be slipped over inner bearing race after inner race has cooled.

4. See that the bearing has proper filling of fresh, clean grease (17 oz. for bearing and housing).

5. Bolt on bearing cap 24 with gasket 17.

6. Collar 13 will be assembled later, see assembly of motors.

Motor Axle Bearings. Cross-sectional view of an axle cap similar to this type of bearing is shown in Fig. 14.

Note: These motors are shipped new with two 0.007 in. shims between the axle cap and frame. When the locomotive has traveled 10,000 miles, these shims should be removed.

Inspection. The bearings should be inspected at regular intervals to check the oil depth. (1¾ in. minimum, 3½ in. maximum, measured on slant.)

1. Clean off all dirt around the waste chamber and oil well covers.

2. Lift covers and examine waste. Change any glazed waste.

3. Make sure that waste is packed tightly against window and that bearing lining flanges are being properly lubricated.

4. Using a suction pump, take a sample of oil from the bottom

of the oil chamber to check for water. If water is found, it should all be withdrawn from the bearings and bearings repacked with fresh waste.

5. Bearings should be repacked after 25,000 to 30,000 miles of service, or every 6 months, whichever comes first.

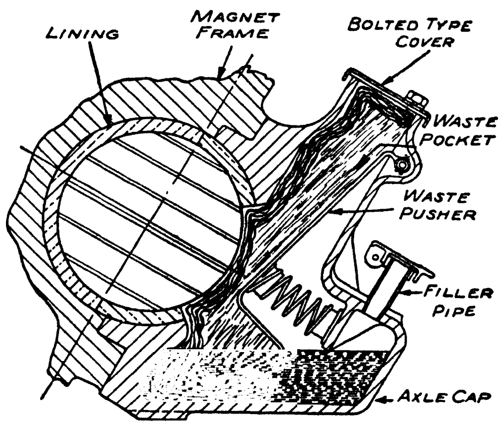


Fig. 14. Large Oil Capacity Axle Cap with Waste Pusher for Traction Motor

Packing Bearings. Empty and clean out waste chamber. Be careful that no dirt drops into it.

These axle caps are fitted with a spring waste pusher. A thin wood or fibre wedge should be inserted between the pusher and the axle to keep the spring compressed while the bearing is packed. If the wedge is inserted in the center of the waste opening, the waste can be packed on both sides of it. The wedges should be removed after packing.

Long fibre wool waste should be used as packing. All the waste to be used should be thoroughly saturated with warm oil for 24 hours and allowed to drain for 12 hours. (Temperature approximately 85 F.)

1. Make several wicks or skeins by twisting the long strands together once or twice.

2. Place the wicks in the window side of the waste chamber so that they extend from the bottom to about 6 in. above the top and force them firmly against the shaft by packing more waste behind them.

3. Fold the top of the wicks back over the packing and fill the remaining space with a wad of waste well saturated with oil to exclude dirt.

Filling the Bearing. 1. Use a good grade of electric car oil. Unless the climate is very uniform throughout the year two grades of oil are required, one for summer and a lighter for winter.

2. Open the oil well cover and gauge the depth of the oil by inserting a clean rod or stick into the auxiliary oil well.

Fig. 15 Micrometer Tool for Measuring "Push-up" of G E. Railway Motor Pinions

3. If the bearing is not sufficiently full, pour oil into the auxiliary oil well until the proper depth of oil is reached (3½ in. maximum measured on slant). 4. Close oil well cover.

Removal and Mounting of Pinions. When removing a pinion, use a suitable pinion puller. Do not heat pinion before pulling and do not use wedges between pinion and bearing cap. In order to prevent damage to anti-friction bearings, avoid unnecessarily heavy blows with a sledge on the pinion puller.

Proper mounting is essential for successful operation of the gearing. Proceed as follows:

1. Thoroughly clean pinion fit of shaft and bore of pinion with benzol. Remove any scoring on either parts, and spot cold pinion on the shaft by hand to obtain at least 75 per cent fit.

2. Mount pinion cold on shaft by hand. Record the position with respect to the shaft, making measurements with a micrometer depth gauge, the method to be similar to illustration, Fig. 15. Mark the points of measurement and mark across the end of the shaft so that after heating the pinion it can again be mounted in exactly the same angular position and measurements made from the same points.

The Zero setting of the depth gauge must not be disturbed until all readings on a particular pinion are completed.

3. Pinions are to be mounted hot on the shaft so as to secure an advance from cold position to hot position along the axis of the shaft as indicated in the table below. This table also gives the estimated difference between shaft and pinion temperatures which will provide this advance. The temperature is estimated only and should be adjusted to maintain the advance within the following limits.

No. of Teeth	Advance	Estimated Temperature Difference
16	0.052–0.062 in.	128 C
18	0.054–0.064 in.	130 C

Temperature of Pinion must never be above 190 C.

A pinion to be mounted should be heated in an oven until the entire pinion has reached a uniform temperature, the required number of degrees above the shaft temperature. Never let the pinion temperature get above 190 C. Shaft and pinion temperatures can best be checked with a hand pyrometer of the type illustrated in Fig. 16.

4. Mount pinion hot in the same angular location as when cold.

5. After pinion has cooled, check pinion position at the marked points with the depth gauge, and make sure the advance is within the above limits. If not within these limits pinion should be removed and remounted.

6. Assemble washer and nut.

Field Coils. When replacing field coils they should be hot drawn. The field coils should be on the pole pieces before heating to avoid damage to insulation by driving a pole piece into a hot coil. The coils may be heated in an oven to 80-85 C. (208-217 F.) temperature for 4 hours, then assembled in the frame and drawn, or they may be assembled in the frame with the pole pieces before heating, then heated by passing approximately 800 amperes through them so as not to bring the coils up to temperature in less than 30 minutes. If heated in an oven, sufficient time should be allowed for the coil to become heated through.

Fig. 16. Hand Pyrometer for Measuring Shaft and Pinion Temperatures

Gear Cases. Remove all grease and dirt when overhauling gear cases. If necessary immerse the gear cases in a solution of caustic potash into which steam is injected and continue until the cases are boiled clean. Repaint with Glyptal No. 1201 Paint.

Under no circumstances should the old grease and oil be burned from gear cases, as this will result in warping them.

Use a good grade of grease of consistency that will adhere to the teeth and level back at operating temperature. Maintain sufficient level in the bottom of the gear case to cover the gear teeth.

Testing After Repairs. Traction motors that have been repaired after running in service must not be given over one-half of the voltage specified for the high-potential test for a new machine. Do not use over 1200 volts for this motor.

TABLE 13. MAINTENANCE DATA FOR GE-731 RAILWAY MOTOR

Type GE-731-B2 (Model 5GE731B2)
Type GE-731-C2 (Model 5GE731C2)

Ratings (per motor) on full field with ventilating covers arranged as in service.

Type of Rating	Continuous	Continuous
Engine Output Hp. for Traction	156	250
Amperes	740	830
Approx. Pounds Tractive Effort	7300	8500
Temperature Rise by Resistance	120C	120C
Cubic Feet Air per Minute	750	1200

The following Data is Common to Both Motors

Resistance at 25 C	
Exciting Field	.00443 ohm
Commutating Field	.00340 ohm
Armature	.00840 ohm
Brush Data	
Pressure	10 to 12 lb.
Size	1-in. by 1⅝-in. by 2¼-in. long
Grade	GE-Grade D3
Clearance and Limits of Wear	
Air Gap, Main Pole	0.125-in. new
Air Gap, Commutating Pole	0.150-in. new
Total End Play, Armature	0.005 min. to 0.015-in. max.
Total End Play, Axle	1/16-min. to 5/16-in. max. (Maximum wear ⅛ in. for each lining flange)
Clearance on Dia. in Axle bearings	1/32-in. nominal to 1/16-in. max.
Radial Clearance, Anti-friction Bearings, Assembled	0.003-in. min. pinion end; 0.0025-in. commutator end
Commutator Side Mica	
Thickness	0.045 in.
Grooving Depth	5/64 in.
Bearing Grease Capacity (Initial Filling)	
Commutator End	10 oz.
Pinion End	22 oz.
Recommended Oil Depth	
Axle Bearings, Measured on Slant	3½-in. max., 1¾-in. min.
Weight of Bare Motor and Pinion	5600 lb.
Weight of Armature and Collars	1540 lb.
Prints and Diagrams	
Bearing Assembly	Fig. 12
Connection Diagram	Fig. 13
Axle Bearing	Fig. 14
Micrometer "Push-up" Gauge for Pinion	Fig. 15
Hand Pyrometer	Fig. 16
Outline Dimensions (GE-731-B2)	Fig. 17
Outline Dimensions (GE-731-C2)	Fig. 18

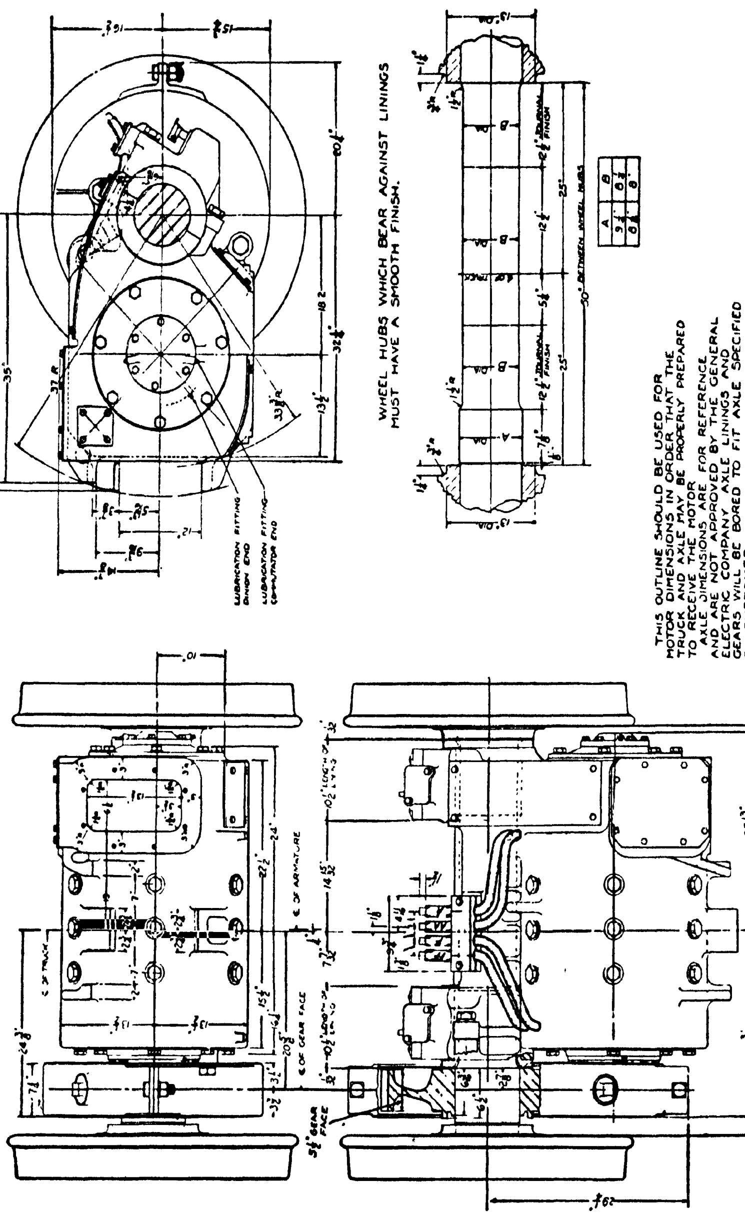


Fig. 17. Outline, Traction Motor, Type GE-731-B2

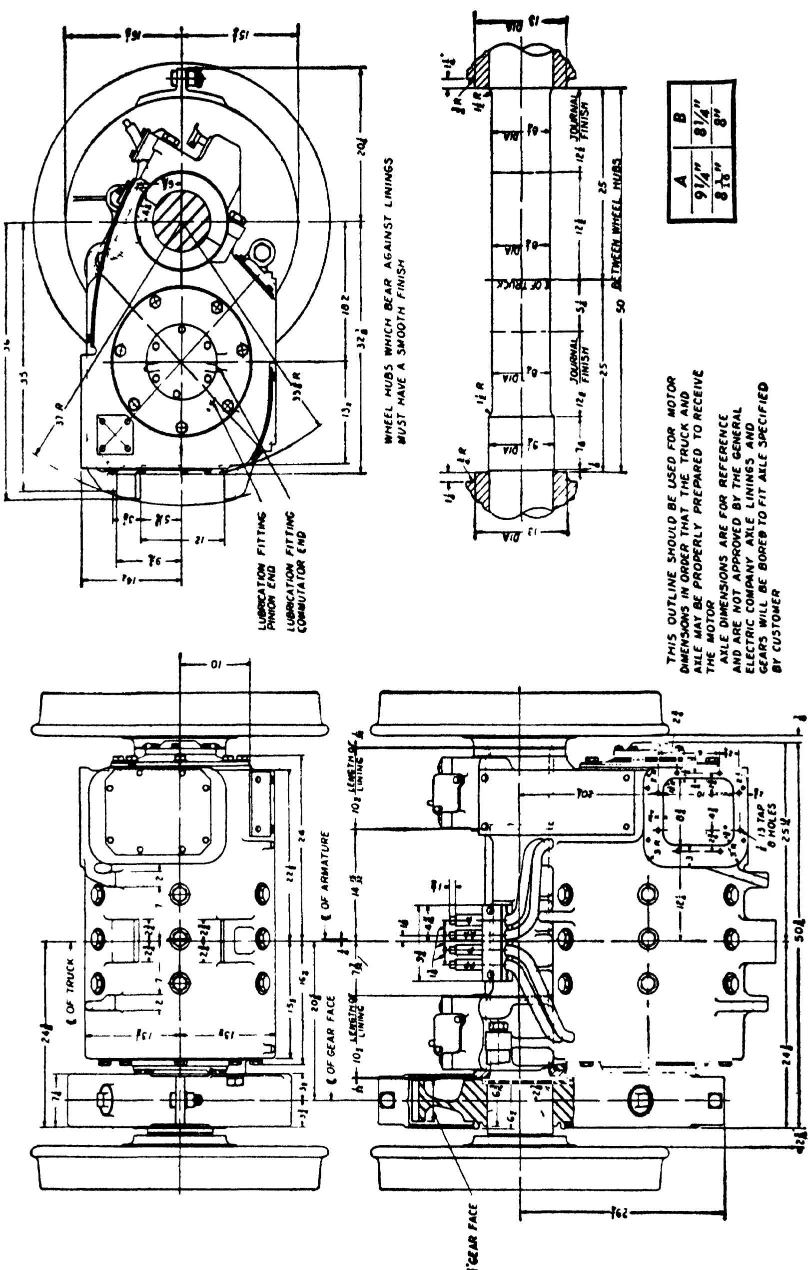


Fig. 18. Outline, Traction Motor, Type GE-731-C2

CONTROL EQUIPMENT

Master Controller (Type C-173-R2) *Function and Description.* The purpose of this controller is to fix the direction of motion of the locomotive. Usually the reverse handle will be thrown clear through to the R.F. (reduced field or field shunt) position. However, "series holding" may be obtained by leaving the handle in the SERIES position and series-parallel operation may be obtained by leaving the handle in the SERIES-PARALLEL position.

There is a magnetic lock in the top of the controller which is energized through the throttle switch and the lock is closed whenever the throttle is moved from the IDLING position, thus making it impossible to pass the OFF position with the controller handle. This makes it impossible to operate the reverser or close the motor circuits with the engine running at more than idling speed.

Inspection. The fingers should be carefully tested so that they drop $\frac{3}{32}$ in. on leaving the cylinder segments, in order to give good contact pressure and still not stub against the cylinder segments.

Fingers should be renewed when worn down about half-way at the contact point.

Lubrication. A thin film of light, high-temperature grease such as Stazrite No. 30 or equivalent should be applied to the cylinder for lubrication at inspection periods to prevent cutting of the fingers and segments. Care should be taken not to use too much lubricant as it will collect under the fingers and cause poor contact.

Maintenance. If it is found that the lock does not function properly; that is, does not close when the throttle is advanced from the IDLING position or does not open when the throttle is thrown into the IDLING position, the tension of the locking spring should be adjusted.

Electro-Pneumatic Contactors (Type 17CP2-J3 or 17CP2-K7) *Function.* These are in the traction motor line circuits and connect the motors to the generator. The series contactor *S* is electrically interlocked with the series-parallel contactors *SP1, SP2* so that the series-parallel contactors cannot close when the series contactor is closed and vice versa. Their sequence of operation is automatic, depending on the position of the controller handle and the speed of the locomotive.

Description. This contactor is of the electro-pneumatic type, being air operated and electrically controlled. Very heavy pressure is obtained at the contact tips, thus insuring low resistance and low temperature at this point. This contactor closes under air pressure operating against a powerful spring. The spring gives a very rapid and positive opening of the tips when air pressure is removed. All parts subject to burning and wear are readily accessible for inspection and replacement.

Maintenance. The contacts should be kept clean and free from any pitting which might develop when interrupting heavy currents. If the contacts do become pitted, they should be smoothed up by light applications of a file.

Extreme care should be taken to insure that full line contact is obtained across and between the two tip surfaces after the filing is completed. If the tips are too badly pitted, they should be replaced.

Contact tips should be renewed when they are worn half-way through.

Lubrication. The cylinder wall and the piston leathers should be lubricated sparingly; only a sufficient amount to keep the leathers pliable.

If the contactor is mounted with its cylinder horizontal, a thin non-freezing oil (G-E PC Control Lubricant No. 1) may be injected into the low pressure end of the cylinder through the oil hole on the side of the cylinder. The total volume of oil should not exceed 1¼ fluid ounces, to avoid leakage around the piston when the contactor closes.

If the contactor is mounted with its cylinder vertical, a grease (G-E PC Control Lubricant No. 2) may be injected into the high pressure end of the cylinder through the plugged opening near the upper end of the cylinder. Oil is not recommended for the high pressure end of the cylinder because it will blow out through the magnet valve.

During the general overhauls of equipment the piston should be removed, the piston leathers replaced if worn or softened by soaking in oil if hard, and the cylinder wall lubricated with G-E PC Control Lubricant No. 2.

Caution: When reassembling a piston a thin shim should be inserted between the piston and the oil inlet in the cylinder wall to protect the piston leathers from abrasion.

Inspection. The operation of the contaotor should be tested occasionally by pressing the magnet valve operating pin. The opening and closing should be rapid. If the operation is sluggish, attention should be given to the lubrication, the condition of piston leathers, the air pressure, and the magnet valve. For care and maintenance of the magnet valve, see Instructions Under the Heading "Magnet Valves."

The movable contact tip is hinged on the end of the contact armature, a compression spring being provided between the two to hold the tip against the inner stop of the armature when the contactor is de-energized. When the contactor closes, this spring compresses, allowing the armature to move after the contact tips touch, with a resultant rolling and wiping motion between the stationary and movable tips. The force required to just move the tip away from the inner stop is known as the initial tip pressure. The force required to move it up against the outer stop is known as the final tip pressure. Both should be measured at the line of contact with the contactor open. To measure the initial tip pressure, insert a thin piece of paper between the movable tip and its inner stop. Attach a spring balance, by means of a wire stirrup and suitable spreader (for clearing the arc chute supporting spring), to the head of the cap screws used for holding the movable contact tip in place. The pull at the instant the paper can be moved is the initial contact tip pressure. To measure the final tip pressure, insert the paper between the movable tip and its outer stop, pulling down on the spring until the paper is held securely. Then gradually release the tension on the spring balance. The pull at the instant the paper can be moved is the final tip pressure.

Tip Gap and Wear Allowance. If a contactor has to be disassembled for any reason, the tip gap and wear allowance should both be checked after the contactor has been reassembled to insure that they come within the limits given under Contactor Data.

The tip gap is the distance between the tips when the contactor is open.

The wear allowance (or "wipe") is a measure of the armature movement after the tips touch. It is the distance the movable tip travels when moving from one stop to the other, measured at the line of final contact.

Magnetic Contactors (Types 17CM12 or 17CM15) *Location and Function.* These are used in the traction motor field shunting, the engine cranking, the battery charging, the generator field or the exciter field circuits. Electrical interlocking assures that they operate in their proper sequence.

Description. These contactors are light weight, single pole, magnetically operated with a bent-up frame construction and using a straight armature with rocker bearing. The contactor must be mounted with its supporting base in a vertical plane and with its contact tips up.

Where necessary, the contactors are provided with blowout coils and arc chutes to assist in rupturing the arc. The arc chute is easily removed, thus making the contact tips readily accessible.

Inspection. The contactor should be manually operated during inspections to detect any mechanical difficulties. Care should be taken that all circuits are de-energized and the battery switch is open before manually closing or doing any work on the contactors.

The copper or alloy contacts should be kept clean and if they become burned or pitted, they should be dressed up by light applications of a fine file. Extreme care should be taken to insure that full line contact is obtained across and between the two tip surfaces after filing. If the tips are too badly pitted, they should be renewed.

Maintenance. The type 17CM12L4 contactor has silver faced contacts which should require little attention. If cleaning becomes necessary use a clean, lintless cloth wet with carbon tetrachloride or use a fine file, not sandpaper or emery cloth. Sandpaper or emery will leave harmful grains in the contact surfaces.

The contact tip final pressure should be checked periodically. To do this, insert a thin piece of paper between the contacts, fully close the armature either mechanically or by energizing the operating oil and attach a spring balance (with wire or string stirrup if necessary) to the head of the screw holding the movable contact

tip. The balance should then be pulled, perpendicular to the line of contact, until the paper can be easily moved. The pull at the instant the paper can be moved is the contact tip final pressure. See Fig. 19.

The tip gap and wipe of the contact tips should be checked periodically. The tip gap is the distance between tips when the contactor is fully open. The wipe, which is measured at the line of final tip contact, is a measure of the armature movement after the tips touch. It is the distance that the movable tip would move from

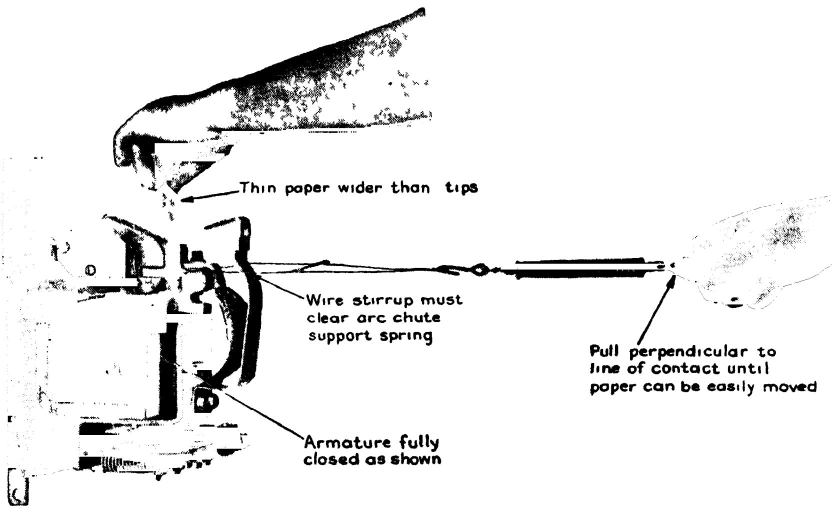


Fig 19. Method of Measuring Final Contact Tip Pressure on GE Transportation Type Magnetic Contactors

its position as it just touches the fixed tip to the position it would assume were the fixed tip not in place when the armature is fully closed against its stop.

The contactor is provided with an adjustable armature spring to obtain positive opening when the operating coil is de-energized. This spring was properly adjusted at the factory and should not require any further adjustment. In the event a contactor is disassembled or the adjustment is otherwise disturbed, the operating coil should be connected to a variable voltage source and the pick-up current checked against that specified under Tables 14 and 15, Contactor Data.

TABLE 14. CONTACTOR CONTACT DATA

Contactor	Symbol on Locomotive Wiring Dia.	Ampere Cont Capacity	Tip Gap or Break	Wipe or Wear Allowance	Contacts Initial Pressure	Contacts Final Pressure
17CM12L4	M1, M2	275	13/32 to 16/32 in.	11/32 to 13/32 in.	2½ to 4 lb.	10 to 13 lb.
17CM12J17	GS1, GS2	275	13/32 to 16/32 in.	11/32 to 13/32 in.	7 to 10 lb.	18 to 22 lb.
17CM15AA12	B, GF	100	11/32 to 13/32 in.	5/32 to 7/32 in.	1½ to 2 lb.	3 to 4 lb.
17CM15CC38	EF	50	18/32 to 21/32 in.	7/32 to 9/32 in.	1½ to 2 lb.	3 to 4 lb.
17CP2J3 17CP2K7	S, SP1, SP2	750	19/32 to 21/32 in.	18/32 to 20/32 in.	12 to 17 lb.	*25 to 35 lb.

*Contact pressure with 70-lb. air—125-lb.

TABLE 15. CONTACTOR OPERATING COIL DATA

Contactor	Symbol on Locomotive Wiring Dia.	Cat. No.	Ohms Resis. at 25 C.	Approx. Pick-up Amperes	Cat. No. Blowout Coil
17CM12L4	M1, M2	2738585	227	0.18	None
17CM12J17	GS1, GS2	4739131	25.2	1.02	None
17CM15AA12	B, GF	2738184	270	0.13	None
17CM15CC38	EF	2738184	270	0.13	2738563
17CP2J3 17CP2K7	S, SP1, SP2	3122101 3040931	775 (J3) 227 (K7)	0.042* 0.075*	

*Values at 70 lb. air pressure.

The copper or alloy contact tips should be renewed when worn half-way through. The silver faced contacts of the 17CM12L4 contactor should be replaced when the silver facing has worn through. The braided copper shunt, which carries the current from the moving contact to the contactor terminal, should be inspected periodically and renewed before it becomes badly worn or broken.

Interlocks. Some of the contactors are provided with electric interlocks.

Those used on the magnetic contactors consist essentially of a contact bar or bars attached to the contactor armature through insulation and contact fingers which are attached to the contactor frame through insulation. Contact pressure, contact wipe and tip gap or break should be checked periodically. It should seldom be necessary to check the exact pressure except when a contact is suspected of being faulty. Wipes, pressures and breaks are given under Interlock Data. Both the stationary and moving contacts are silver faced and should require very little attention. If any cleaning is necessary, use a clean, lintless cloth wet with carbon tetrachloride or use a fine file, not sandpaper or emery cloth. Sandpaper or emery will leave harmful grains in the contact surface.

The sliding type of interlock is used on the 17PC2 contactors and consists of contact segments and contact fingers which are attached through insulation to the contactors. Contact pressure should be checked periodically. The contacts should be kept clean and free from pitting. Replace fingers when they are worn half-way through.

Refer to Table 16 Interlock Data for adjustments and cross reference to devices interlocks are used with.

Electro-Pneumatic Reverser (Type ME-57-A5 or E5) *Function.* The reverser changes the connections to the traction motors fields and thus reverses the direction in which the motors will rotate.

Description. It is operated by a double cylinder air engine controlled by two "on" type magnet valves. The reverser is interlocked so that it cannot be operated except with the motor contactors open. As the reverser does not break any current, there should be no burning of the contacts. Any roughness that may develop due to other causes should be removed with a file.

TABLE 16. INTERLOCK DATA

Type*	Used On		Wipe	Tip Gap or Break	Pressure
	Type	Symbol			
17AF4A3	17CP2	<u>S</u>, <u>SP1</u>	†	†	2 to 5 lb.
17AF4A4†	17CP2	<u>SP2</u>	†	†	2 to 5 lb.
17AF14H1	17CM12L4	<u>M1</u>	3/32 to 4/32 in.	7/32 to 9/32 in.	over 8 oz.
17AF14H3	17CM12J17	<u>GS1</u>	3/32 to 4/32 in.	7/32 to 9/32 in.	over 8 oz.
17AF14H9	17CM12J17	<u>GS2</u>	3/32 to 4/32 in.	7/32 to 9/32 in.	over 8 oz.
17AF14F9	17CM15AA12	<u>B</u>	3/32 to 4/32 in.	4/32 to 6/32 in.	over 8 oz.
17AF14F3	17CM15AA12	<u>GF</u>	3/32 to 4/32 in.	4/32 to 6/32 in.	over 8 oz.
17AF14K1	17CM15CC38	<u>EF</u>	3/32 to 4/32 in.	7/32 to 8/32 in.	over 8 oz.
17AF14F1	17LV40H9	<u>GR</u>	3/32 to 4/32 in.	3/32 to 4/32 in.	over 8 oz.

*Interlocks are listed in the order in which they appear in the "List of Apparatus" on the Locomotive Wiring Diagram.

† For the 17AF4 interlocks, the fingers must slide onto the segments at least 1/8 in. and must not go within 1/8 in. of opposite side. There must be at least 1/8 in. between finger and stop to give a minimum wear allowance of 1/32 in.

Inspection and care. Frequent inspections should be made to guard against weak fingers, poor contacts and loose connections. The contacts should be cleaned when necessary and lubricated with a thin film of light, high temperature grease such as Stazrite No. 30 or equivalent. The bearing grease cups should be kept filled with a good grade of cup grease and periodically tightened to insure that the bearings are properly lubricated.

The reverser should be tested for operation by pressing the valve pins in the top of the magnet valves. If the operation is sluggish and the segments and bearings are well lubricated, the cylinders and piston packings are probably dry and should be greased, using G-E PC Control Lubricant No. 2.

Sluggish action of the reverser may also be caused by sticky or leaky magnet valves.

Main and control contact fingers should be periodically inspected (and adjusted if necessary) to insure that the pressures are within the limits specified under Table 17. In all cases, it is necessary that good contact be made between the fingers and segments.

About ⅛-in. wear is allowable on the main fingers while the control fingers should be replaced when worn half-way through.

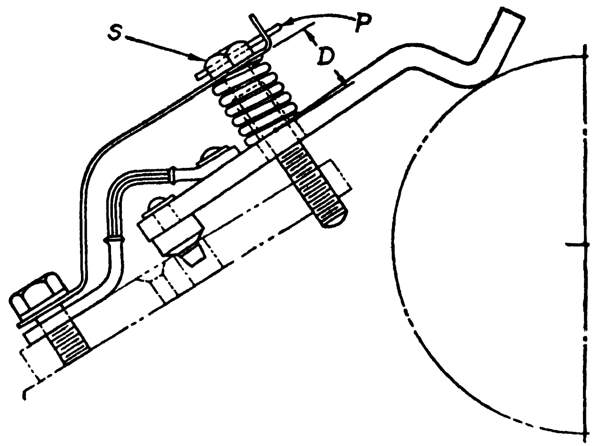


Fig. 20. Finger Adjustment for Type ME-57 Reverser

Reverser Finger Should Be Adjusted in the Following Manner:

(a) Remove Cotter Pin, *P*.

(b) Turn Screw *S* until space between Finger and Locking Plate at *D* is equal to $\frac{3}{32}$″. This Distance Should Give a Pressure on the Finger Tip between 15 lb. to 20 lb. when finger is new.

(c) Insert Cotter Pin, *P* in Holes of Locking Plate and Screw.

For adjustment of main fingers, refer to Fig. 20.

Refer to the Instructions Under Magnet Valves for information on the valves used on this reverser.

TABLE 17. TYPE ME-57A5 OR TYPE ME57-E5 REVERSER DATA

1. Amperes continuous capacity (per motor circuit)	750 amp.
2. Contact pressure for individual main fingers	15 to 20-lb.
3. Contact pressure for control fingers	2 to 5-lb.
4. Magnet valve operating coil:	
(a) Catalog No.	3046106
(b) Ohms Resistance at 25 C.	886

Magnet Valves. These magnet valves are used to operate the reverser and the air operated contactors. They are all of the "on"

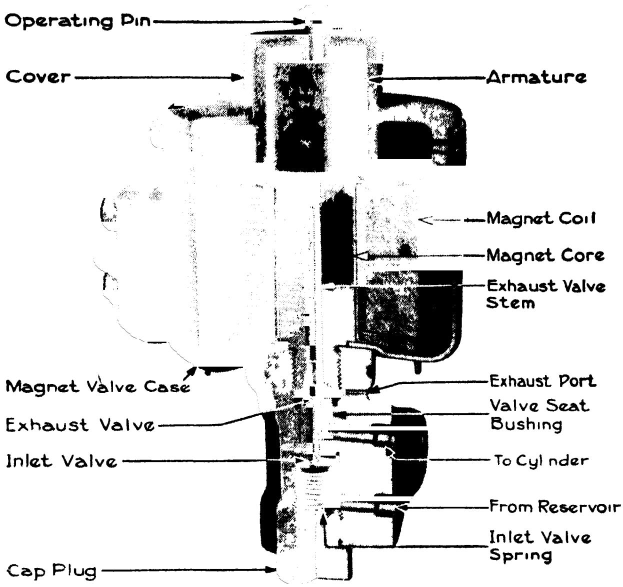


Fig 21 Enclosed Coil, "ON" Type Magnet Valve

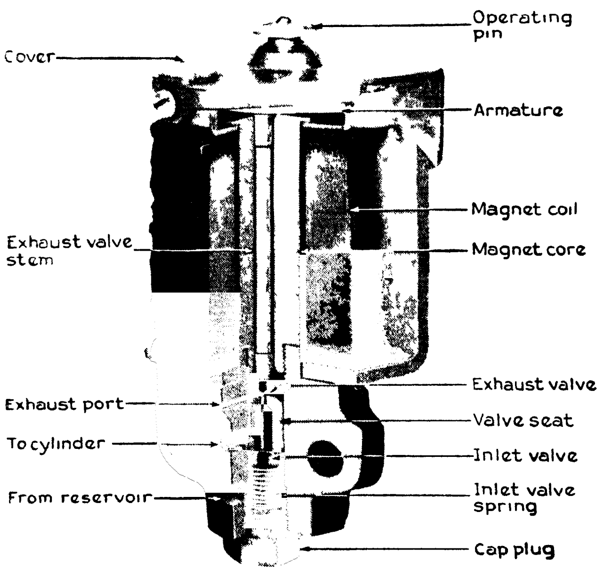


Fig 22 Open Coil, "ON" Type Magnet Valve

type. The cross-sectional view of the enclosed coil valve is shown in Fig. 21, while Fig. 22 shows the cross-sectional view of the open coil valve.

Description. This valve is of the double-acting type and has an inlet and an exhaust port, as well as a port for connecting to the operating cylinder.

This valve is so constructed that when the coil is energized the exhaust port is closed and the inlet port is open, thus admitting air

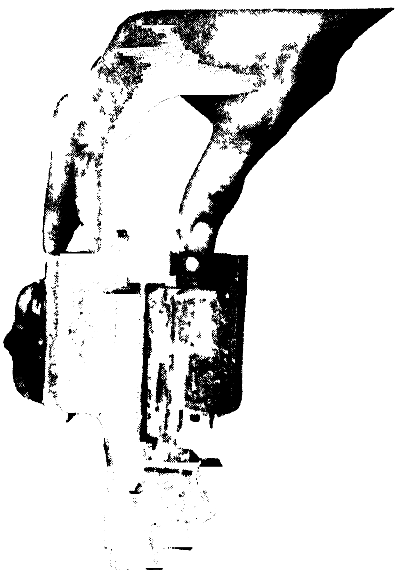


Fig 23 Enclosed Coil, "ON" Type Magnet Valve with Parts Cut Away and with Gauge Cat. 1499733 in Proper Place for Checking Valve Stem Travel

from the reservoir to the operating cylinder. When the coil is de-energized the inlet port is closed and the exhaust port is open connecting the cylinder to atmosphere.

Cleaning. When the valves are sticky, they should be washed with kerosene or other petroleum cleaner. Also pour a little cleaner through the magnet core to clean the valve seat. When valves are removed, care should be taken to insure that each valve is returned to its own seat, as each stem is ground to fit its own seat.

When a new valve is installed, or when repairing a leaky valve, it must be ground in. After a good seat is obtained all of the grind-

ing material should be blown out with air and the valve washed with the above cleaner. When a large number of valves are to be ground, the cost may be reduced by using special reamers in the valves and valve seats before the valves are ground in.

Measuring Air Gap and Travel. The air gap and travel of the magnet valve should be periodically measured. Gap gauge, (See Fig. 23 and Fig. 24) is arranged with four measuring gaps and

Fig 24. Open Coil "ON" Type Magnet Valve with Gauge Cat. 1499733 in Proper Place for Checking Valve Stem Travel

should be used for this check. This also applies to the adjustment of new valves. The measurements are made by removing the magnet valve cover and armature. The 0.032-in. gap of the gauge is placed over the upper valve stem or plunger and pressed down. This should seat the exhaust valve; that is, air should not escape through the exhaust valve. If air passes through, new valves should be installed.

The valve travel is stamped on the bottom surface of the cap plug on the magnet valve.

Installing New Valves. When installing new valves, the following measurements should be taken, using a gap gauge, Cat. 1499733.

1. Place the 0.052-in. gap over the exhaust valve stem and press down. If the valve stem is of the correct length, the exhaust valve will seat and air will not pass through it and the legs of the gauge will rest on top of the magnet core. If these conditions are not satisfied, the valve stem should be lengthened or shortened. When the exhaust valve stem is found to be too short, it can be lengthened a trifle by carefully peening the upper end.

After the exhaust valve seat has been ground in a number of times, it may be found that an exhaust valve stem of standard

Fig. 25. Micrometer Dial Gauge for Adjusting Magnet Valve. Adjusting Gauge Dial to Zero on a Flat Surface Before Use

length is too short and the adjustment called for above cannot be obtained. In this case an over-length valve stem should be used. Valve stems will be found listed in the Supply Catalog, and are supplied $\frac{1}{16}$-in. longer than the ones furnished with new valves.

2. Use 0.088-in. gap for valves with 0.036-in. travel; 0.104-in. gap for valves with 0.052-in. travel. Place the proper gap over the exhaust valve stem with the gauge legs resting on the magnet core top. If the inlet valve stem is of the proper length, the upper or exhaust valve stem will be flush with the gap surface and air will not pass through the inlet valve. If air passes through the inlet valve, remove a small amount from the inlet valve stem. If there is a space between the top of the exhaust (upper) valve stem and gauge gap, install an inlet valve with a longer stem.

Checking Worn Valves. To check worn valves, place the 0.032-in. gap over the exhaust valve stem and press down. If the

exhaust valve does not seat (that is air passes through the valve), install a new valve and take measurements as described above.

In order to do this work quickly, it is advisable to remove the magnet valve from the apparatus. This can be done quite readily by taking out the two cap bolts near the bottom of the valve.

A more accurate method of measuring valves is by the use of a standard micrometer gauge with a special fixture, and the method of using is illustrated in Figs. 25 and 26. This is especially convenient where there are a large number of valves to be overhauled,

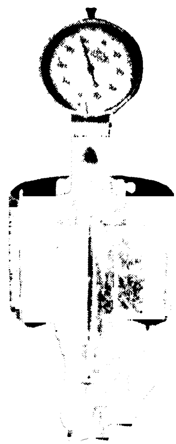


Fig. 26. Method of Using Micrometer Dial Gauge on Magnet Valves

as the amount of material to be removed from new valves can be determined directly rather than by a cut and try process.

The proper valve stem length as measured above the magnet valve core are as given above and under Magnet Valve Data, Tables 18 and 19.

TABLE 18. MAGNET VALVES, WHERE USED

Type or Cat No.	Apparatus Used On
17MV1A5	17CP2K7 Contactors
17MV1A6	17CP2J3 Contactors
17MV23A4	17MK3L9 Throttle Mechanism
TE-49-C2	17ME2A6 Sander Valve
4758437	ME-57-A5, E5 or E6 Reverser

TABLE 19. MAGNET VALVE DATA

Type or Cat. No.	Travel	Operating Coil			
		Cat. No.	Resis. at 25 C.	Current to Operate at Air Pressure	Continuous Current
17MV1A5	0.036 in.	3040931	227 ohms	0.075 amp. at 70 lb.	0.25 amp.
17MV1A6	0.036 in.	3122101	775 ohms	0.042 amp. at 70 lb.	0.133 amp.
17MV23A4	0.036 in.	4739157	800 ohms	0.049 amp. at 90 lb.	0.108 amp.
TE-49-C2	0.036 in.	2738184	290 ohms	0.25 amp. at 125 lb.	0.5 amp.
4758437	0.036 in.	3046106	886 ohms	0.075 amp. at 100 lb.	0.135 amp.

	Enclosed Coil Type	Open Coil Type
1. Photographs		
"On" Valve	Fig. 21	Fig. 22
"On" Valve with gauge Cat. 1499733	Fig. 23	Fig. 24
Micrometer Gauge—		
Zero Adjustment	Fig. 25	Fig. 25
Method of Use	Fig. 26	Fig. 26
2. Four sided measuring gauge†	Cat. 1499733	Cat. 1499733
3. Wrench of magnet core	Cat. 260513	Cat. 260513
4. Micrometer Gauge	Cat. 2812735	Cat. 2812735
5. Gauge Gaps to be used:	0.036-in.	0.052-in.
(a)—New Valves	travel	travel
(1) Valve de-energized	0.088 in.	0.104 in.
(2) Valve energized	0.052 in.	0.052 in.
(b)—Worn Valvès		
(1) Wear Limit	0.032 in.	0.032 in.

†When using this gauge the feet of the gauge must rest on the magnet core.

Control Relay—CR1 (Type 17LV40D6) *Function.* This relay in conjunction with the motor transfer and field shunting control relay controls the transition of the motor circuits from series to series parallel.

Description. It is of the contactor type, having a rocker bearing type armature which carries a set of two contact fingers connected together. These fingers make contact with two stationary contact studs when the relay is de-energized and make contact with two other stationary contact studs when the relay is energized, thus providing one circuit in each direction.

Adjustments. This relay was factory adjusted to pick up at 0.130 amp. It should drop out at approximately 25 per cent of pickup.

The pickup of the relay can be adjusted by changing the tension of the hinged armature spring. Increasing the tension raises the pickup, while decreasing the tension lowers the pickup.

Inspection. The relay should be periodically examined to insure that there are no loose or excessive worn parts. Inspect the terminals to insure that they are tight.

The contacts of the relay are silver faced and should seldom require attention. If any cleaning is necessary, use a clean, lintless

TABLE 20. TYPE 17LV40D6 RELAY DATA

1. Contact Data	
(a) Tip Gap	7/32 to 8/32-in.
(b) Wipe	3/32 to 1/8-in.
(c) Minimum tip pressure	6 oz.
2. Coil Data	
(a) Cat. No.	2738184
(b) Res. at 25 C	270 ohms
(c) Pick-up current (set to)	0.13 amp.
(d) Dropout current	approx. 25% of pickup

cloth wet with carbon tetrachloride or use a fine file, not sandpaper or emery cloth. Sandpaper or emery will leave harmful grains in the contact surface. Replace contacts when the silver facing has worn through.

The contact gaps and wipes should be checked periodically against the values given in Table 20.

Grounding Relay—GR (Type 17LV40H9) *Function.* This relay is used for grounding the negative side of the traction generator and motor circuits. The relay and interlock contacts are connected respectively in the control circuits of the generator field and exciter field contactors. The relay was factory adjusted to pickup and lock out at 10 amps.

Description. This relay is of the contactor type, having a hinged armature which carries two contact fingers connected together. These fingers make contact with two stationary contact studs when the relay is de-energized. The armature latches close when the relay is energized and must be reset manually.

The type 17AF14F1 Interlock at the bottom of the relay provides an additional closed circuit when the relay is de-energized.

Operation. When the relay picks up the cause should be determined before the latch on the relay is tripped. Never trip the latch unless the controller is in the idling position. If it is found that the positive side of the generator-motor circuit has become permanently grounded, it is possible to disconnect the grounding relay

TABLE 21. TYPE 17LV40H9 RELAY DATA

1. Contact Data	
(a) Tip Gap	12/32 to 13/32-in.
(b) Wipe	3/32 to 3/42-in.
(c) Rating of contacts at 600 volts	0.08 amp.
(d) Tip Pressure	6-oz. minimum
2. Coil Data	
(a) Cat. No.	4739145
(b) Res. at 25 C	0.0735 ohm
(c) Pick-up current	(Set at) 10 amps.

by means of the SPST knife blade switch and continue operation with the positive side of the circuit grounded, provided the generators and motors have not been damaged. This connection is provided for emergency use only and the normal connection should be restored as soon as possible.

This relay is similar to the 17LV40D6 relay CR1 and the same instructions on maintenance and adjustments will apply.

Reverse Current Relay—RC (Type 17LC19D5) *Function.* This relay is used to control the battery charging contactor. The

operating coil of this contactor will be energized when the auxiliary generator voltage is greater than battery voltage and will be de-energized when the auxiliary generator voltage is less than battery voltage.

Description and Operation. The relay consists of three coils on three magnetic cores mounted on a common steel base. A flat knife edged steel armature pivots around the center core causing contact to be made. There are special accurate machined fixed air gaps at the bases of the lower two cores. A compression spring returns the armature to the de-energized position while a non-magnetic stop screw limits the travel when energized. The top or shunt coil is connected across the charging generator armature in series with resistance which is partially shorted out by a normally closed interlock on the battery charging contactor for pickup. The middle or series coil is connected in the main circuit between the

TABLE 22. TYPE 17LC19D5 RELAY DATA

1. Contacts (Adjustment)
   (a) Tip Gap .... 1/16-in.
   (b) Wipe .... 1/16-in.

Coils	Shunt	Series	Differential
(a) Cat. No.	4739205	6724050	4739206
(b) Res. at 25 C......	29.4	.00287	279
(c) Pickup	Battery +3	0	3 volts or less
(d) Drop out	72 volts	8.5 amps or less	0

generator and the battery. The lower, or differential coil is connected across the battery charging contactor contacts with a resistor in series. This resistor is part of the resistor in series with the shunt coil.

The polarity of the shunt and differential coils is so arranged that with the auxiliary generator voltage less than battery voltage, the magnetic flux in the differential core will be additive, thus sealing the armature in the open position and thereby preventing the battery charging contactor from closing. When the auxiliary generator voltage becomes higher than the battery voltage, the magnetic flux reverses and breaks the seal, thus allowing the armature to move to the closed position and operate the battery charging con-

tactor. This operation will occur when the auxiliary generator voltage is 3 volts (or less) greater than the battery voltage.

Mounting. The relay is mounted with the axis of the coils horizontal and with the contacts down.

Coil Settings. Slight changes in the setting may be made with the armature compression spring, but it is mainly determined by the air gaps in the differential and series cores. These air gaps are set at the factory and should require no attention. The 3 volts differential required to operate the relay is nearly constant over the entire range of expected battery voltage. When the battery charging contactor is picked up, its interlock inserts resistance into the shunt coil circuit. The series coil is so connected that while current is flowing from the auxiliary generator to the battery it will aid the shunt coil in holding the armature in the closed position. However, when the auxiliary generator voltage decreases below the battery voltage and the current reverses, the shunt and series coils will buck out the armature, thus opening the battery charging contactor. This value of "buck out" current may be increased by backing out the armature stop screw and decreased by running the stop screw in. When decreasing the buck out current with the stop screw, care must be exercised that the current is not lowered to the point where pumping will occur on pickup of the relay.

Adjustment Procedure. The relay is adjusted for the following sequence and current value.

1. Apply 0.14 amperes to differential coil.
2. Apply 0.567 amperes to shunt coil.
3. Decrease differential coil amperes to zero, reverse, and pickup should occur at less than .008 amperes. To make slight adjustments use compression spring.
4. Open differential coil circuits, and decrease shunt coil amperes to obtain drop out at 0.079 amperes by adjustment with stop screw.
5. Apply 0.135 amperes to shunt coil, pick up armature by hand, then check that less than 8.5 amperes in the series coil will "buck out" the armature.

The relay should be inspected periodically to see that the armature is free from binding. The contacts are silver faced and should

require little attention. If it becomes necessary to clean the contacts, use a clean, lintless cloth wet with carbon tetrachloride or use a fine file. Do not use sandpaper or emery cloth as they will leave harmful grains in the contact surface.

All of the coils can be removed from the front of the relay by first removing the two screws at the top of the center core. If the cores are removed care should be taken so that the bases of the cores are not damaged.

Traction Motor Transfer and Field Shunting Control Relay— V (Type 17LC18E2) *Function.* This relay is provided to control the traction motor connections and field shunting contactors. It automatically transfers the motors from series to series-parallel and operates the field shunting contactors at the proper time providing the master controller handle is in the full forward or full reverse position.

Description. An insulated base supports an inverted **T**-shaped magnetic frame to which a double acting balanced armature is pivoted. Each end of the armature has an adjustable plunger, each plunger being acted upon by a separate coil attached to the frame. The armature carries 2 insulated blocks with a normally open contact finger attached to each block. The outer end of the frame supports an insulated block to which the stationary contacts and armature spring are attached.

Mounting. The relay is mounted with its base vertical and with the armature spring below armature hinge pin.

Operation. With both coils de-energized the contacts are held in the open position by the armature spring, which forces the lower plunger against its core. The upper (shunt) coil is connected, in series with suitable external resistors, across the traction generator armature and thus its current is proportional to generator voltage. The lower (series) coil is connected in parallel with the traction generator and exciter series field windings and its current is proportional to generator current. With no current in the series coil, the relay operates as a simple potential relay, with the armature spring being the only opposing force. When the series coil is energized, it also opposes the shunt coil and thus increases the shunt coil current required to operate. Thus the relay will operate at relatively

low voltage with no load on the generator and the pickup voltage increases rapidly with increasing generator current.

Calibration. Mount the relay with base vertical and armature spring below armature hinge pin and proceed as follows:

1. Adjust both movable plungers so that with both plungers touching their fixed cores, the finger insulation blocks have the same clearance from the coils. Then back out each movable plunger two complete turns and lock with locking nut.

2. Adjust contact tips to have $\frac{1}{16}$-in. wipe when upper plunger is held against its core (but armature to stop on core and not on finger shield). The tip gap must be at least $\frac{1}{16}$-in.

3. Connect the operating coils to suitable power supply through individual adjustable resistors, making sure that the polarity is the same as shown on the wiring diagram (diagonally opposite terminals should have the same polarity).

4. Adjust the current in the series coil to 1.0 amperes and then adjust the armature spring until the relay will pickup (close its contacts) at .157 amperes in the shunt coil. With 1.26 amperes in the series coil, the drop out current should be from .030 to .040 amperes. With relay set for the above pickup and drop out, the relay should pick up with zero series coil current at .052 to .058 amperes through shunt coil and drop out with zero series coil current at less than .020 amperes. If relay operation does not meet the above values, the upper plunger and the armature spring should be adjusted to obtain these values. If any change is made to plunger position or spring setting, all of the above four sets of operating

TABLE 23. TYPE 17LC18E2 RELAY DATA

1. Contact Data		
Min. tip wipe		1/16-in.
Min. tip gap		1/16-in.
2. Operating Coils		
Operating coils	Shunt Coil	Series Coil
Resis. at 25-C.	4739102	4739103
Cat. No.	550-ohms	1.41-ohms

values should be checked. No adjustments should reduce the tip gap and tip wipes below the minimum limit of $\frac{1}{16}$-in. and no adjustment should cause the relay armature to stop any place except on the relay cores.

5. Check all adjustments to insure that all locking nuts are properly tightened.

Maintenance. Operate the relay manually several times to insure that the armature moves freely on its pivot and that the armature is returned positively to its open position with its lower movable plunger striking its stationary core. Also check that with the armature in the open and closed position that there is a minimum of 1/16-in. between the armature counter-balance edges and the operating coils. A slight amount of play in the pivot is permissible, but in no case should this be sufficient to permit the plungers to rub against the sides of the coils. Check contact fingers for proper wipe and gap. The contacts are silver faced and should seldom require attention. If any cleaning is necessary use a clean, lintless cloth wet with carbon tetrachloride, or use a fine file, not sandpaper or emery cloth. Sandpaper or emery will leave harmful grains in the contact surface.

Current Limit Signal Relay CL (Type 17LS7C3) *Function.* Operation of this relay lights the signal light warning the engineers that the equipment is overloaded.

Description. This type of relay consists of a series operating coil mounted upon an open type magnetic structure and has a light-weight counter-balanced operating mechanism with small travel to obtain rapid operation and accurate adjustment. The hinged armature, which carries an adjustable core, has a contact arm which is arranged to make contact with either of two stationary contact studs. An adjustable armature spring is provided.

Adjustment. The relay coil is connected in series with the traction motor circuit. It was factory adjusted to pickup at 700 amps. for the 660 hp. unit and 900 amps. for the 1000 hp. unit.

The contact tips should have 3/64 to 4/64-in. gap. The wipe should be at least 1/32-in.

Inspection. This relay is similar to the type 17LV24E1 and the same instructions and adjustments will apply.

Voltage Control Relay—X (Type 17LH22C1) *Mounting.* The cabinet where the relay is installed should be well ventilated and reasonably free from dirt, moisture, and oil vapors. The coils and resistors dissipate 250 watts.

The cover is positioned at the top by two locating pins, and fastened at the front bottom by a half turn bayonet type fitting. Sufficient space should be left for removal of the cover and for access to the contacts.

Application. The relay is a dynamic type, voltage regulating device, equipped with a counterweight for smooth operation under rough track conditions. Constant voltage is held on the auxiliary

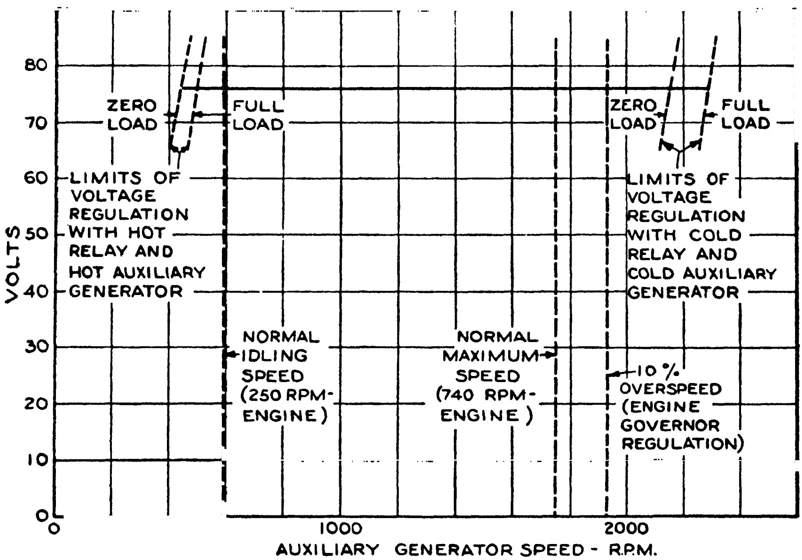


Fig. 27. Auxiliary Generator Voltage Speed Characteristics

generator unit of the GMG-139-A exciter-auxiliary generator set, over the normal speed and load range. See Fig. 27.

An ample resistance range of from 90.4 to 0 ohms is provided. Table 24 illustrates average conditions for a nominal 76-volt setting.

Description. Fig. 28 shows the assembled relay, Fig. 29 the operating mechanism, Fig. 30 the floating coil and supports, and Fig. 31 a cross section view of the magnetic structure. Internal connections are made with asbestos covered solid copper conductors.

The central core holds the fixed coil inside the steel tube. Four spring steel fingers position the floating coil in the circular air gap. These fingers permit frictionless longitudinal coil motion, but resist sideward displacement.

TABLE 24. 76 VOLT SETTING FOR VOLTAGE CONTROL RELAY

Auxiliary Generator						Relay	
Armature			Shunt Field			Effective Resistance Ohms	No. of Contacts Closed
Speed R.p.m.	Volts	Load Amps.	Temp. C.	Res. Ohms.	Average Amps.		
1750	76	0	25	10.81	0.93	68.5	1
1750		66	75	12.9	1.02	61	2
595		0	75	12.9	3.25	9.5	10
595		66	75	12.9	3.98	5.45	12

A pair of external tension springs hold the floating coil in its outward position. The front spring rod links the counterweight to the floating coil.

A wedge shaped contact bar is carried by the floating coil. The bar has a slope such that successive hinge type, stationary contact fingers are commutated progressively as the floating coil moves in or out.

OPERATION. 1. Connections. Fig. 32 shows the fundamental schematic connections. The auxiliary generator shunt field is separately excited from the locomotive battery through the relay field resistors and contacts.

The relay voltage responsive circuit is that through the floating coil shunt winding and the control resistors. This is connected across the auxiliary generator armature. The current in this circuit is proportional to the auxiliary generator voltage. For convenience in operating, the fixed coil is connected in parallel with the floating coil.

2. *Control of Voltage.* When the fixed coil is energized, lines of magnetic flux are set up in the magnetic structure and these same lines pass across the circular air gap in which the floating coil operates.

The current in the floating coil creates a motive force tending to move the coil inward against the tension springs. The amount of tension fixes the current required to move the coil. The amount of

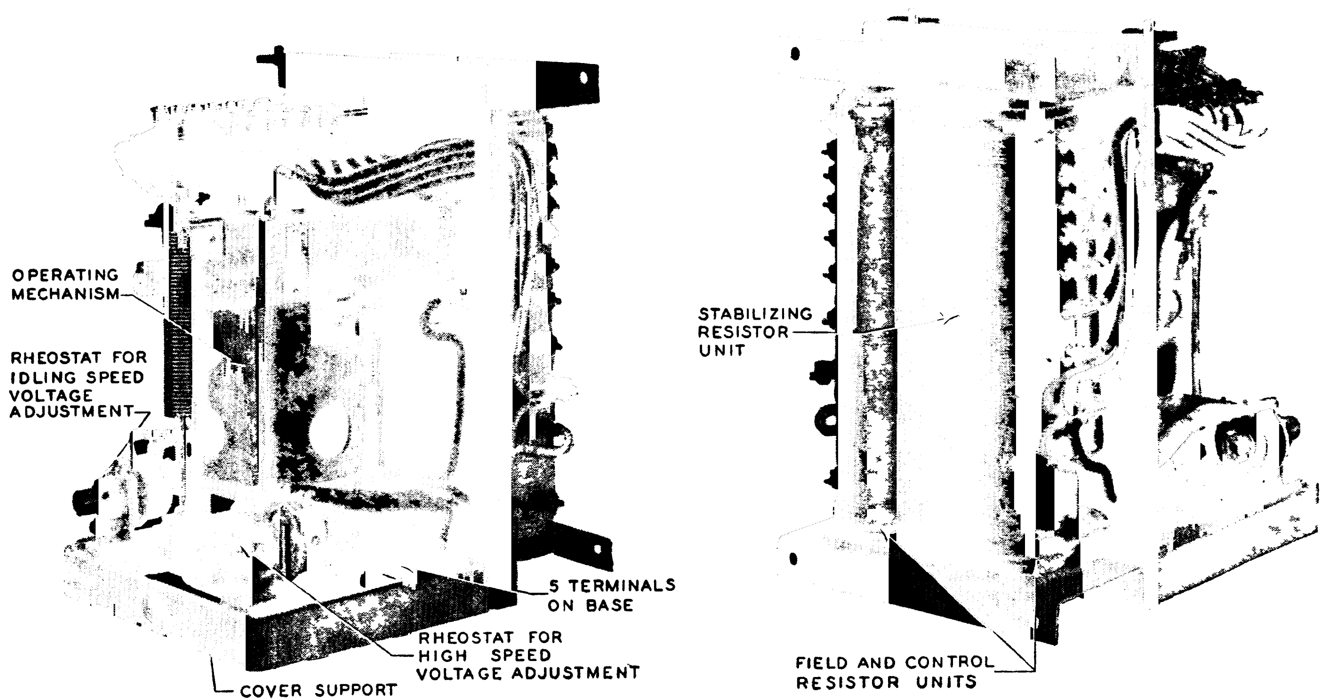


Fig 28 Voltage Control Relay for Auxiliary Generator, Right and Left View without Covers

control resistance in circuit determines the voltage needed to create this current, and fixes the relay voltage calibration value. Adjustment is made by means of the dial rheostat provided.

Whenever the auxiliary generator voltage exceeds the calibration value, the floating coil moves inward, carrying the contact bar

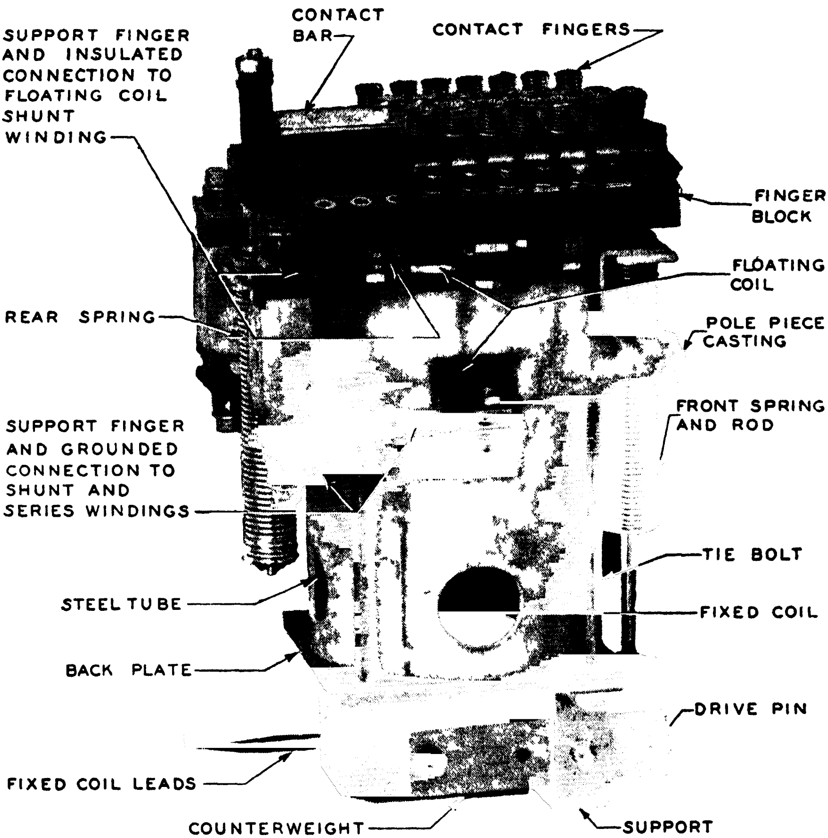


Fig 29 Operating Mechanism of Voltage Control Relay for Auxiliary Generator

away from successive contact fingers, until sufficient resistance has been cut into the shunt field circuit to restore the voltage to normal. The opposite action takes place upon a decrease in voltage.

At any fixed speed and load the floating coil remains stationary, except where a field resistance value is required midway between that obtained from neighboring contacts. This condition is satisfied

by a pulsating coil movement that rapidly opens and closes one of the contacts to obtain the desired effective resistance.

3. *Stability.* Unnecessary overshooting and complete absence of pumping is obtained by the loose coupling of the floating coil to the auxiliary generator shunt field through the stabilizing resistors.

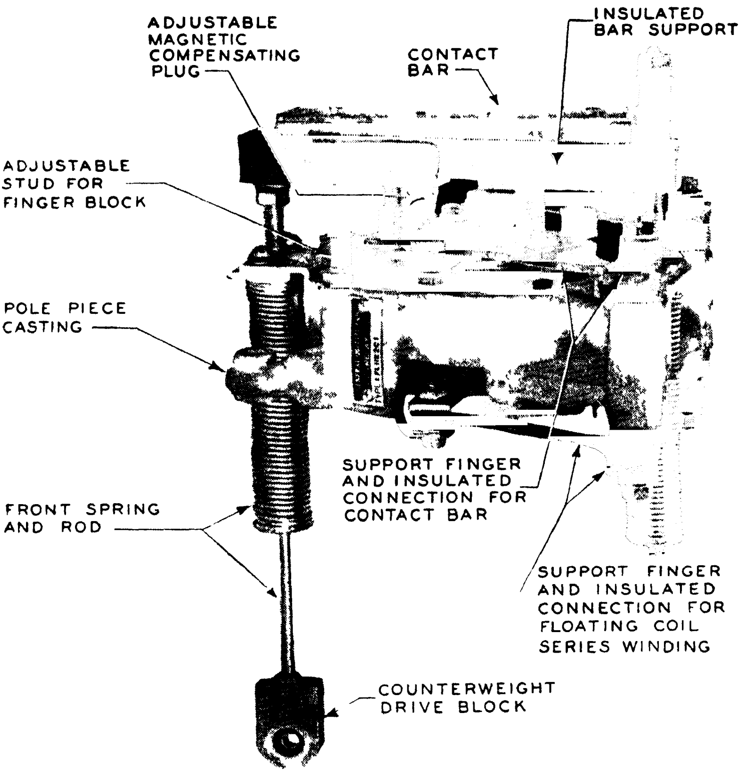


Fig. 30. Floating Coil and Supports of Voltage Control Relay for Auxiliary Generator

The induced field voltage, occurring when a contact opens or closes on the bar, forces a corresponding change in floating coil current in a direction opposing further coil movement. Good stability is obtained over a wide range of stabilizing resistance.

The positive ends of the floating and fixed coils are separated by a small amount of resistance for further aid to stability. This is obtained by a tap near the end of the stabilizing resistor unit.

TABLE 25. HOT AND COLD RESISTANCES OF RELAY COILS AND RESISTORS

A		B	INDEX		C	D		E	
Cold		Cold	Temperature*		Hot	Hot		Hot	
High			Aux. Generator Speed			High		Idling	
0			Aux. Generator Load			0		Full	
1			Number of Relay Contacts Closed			1		12	
A	V	Ohms	Items	Reference	Ohms	A	V	A	V
0.93	10.07	10.81	Aux. Generator Shunt Field		12.9	0.93	12.01	3.98	51.54
0.957	65.7	90.4 Max. 0 Min.	Two Field Resistor Units Sections A, B, C, D, E, F, and G	Cat. 4737970 See Fig. 37	90.4 Max. 0 Min.	0.96	63.7	4.26	23.24
0.93 0.44	0.23 6.27	0.245 14	Floating Coil–Series Winding –Shunt Winding	Cat. 4739182	0.306 17.5	0.93 0.46	0.29 8.05	3.98 0.61	1.22 10.65
0.027 0.413	2.3 6.2	100 Max.	Stabilizing Resistor–85 ohm sect. –15 ohm sect.	Cat. QLK-5901245G2	100 Max.	0.028 0.432	2.38	0.281 0.329	23.9 4.94
0.27	1.56	75 Max.	Stabilizing Rheostat (Idling Speed Adj.) Average setting 60-ohms	Ohmite Model H Cat. 0150	75 Max.	0.028	1.68	0.281	16.8
1.23	12.47	10.15	Fixed Coil	Cat. 4739181	12.7	1.145	14.55	1.225	15.6
1.64	29.2	17.8	Two Control Resistors–Section H of Cat. 4737970	See Fig. 37	17.8	1.58	28.1	1.55	27.6
1.64	5.6	8 Max.	Control Rheostat (High Speed Adj.) Average setting 3.4 ohms	Ohmite Model H Cat. 0144	8 Max.	1.58	5.37	1.55	5.3

*Cold values at 25 C. Hot values at normal operating temperature and 25 C. ambient. Under abnormally hot conditions, the auxiliary generator field resistance may increase, and the stabilizing rheostat (idling speed voltage adjustment) may have to be increased. Values in Column E will change proportionately.

Use Columns A and B for high speed, O load, with a cold auxiliary generator and relay.
Use Columns C and D for high speed, O load, with a hot auxiliary generator and relay.
Use Columns C and E for idling speed, full load, with a hot auxiliary generator and relay.

4. *Compensation.* The relay is compensated for flat voltage regulation over its entire range, under average conditions, by means of a small series winding on the floating coil. This winding carries auxiliary generator shunt field current, and is wound with opposite polarity to that of the shunt winding.

The series winding bucking effect is proportional to the number of contacts closed on the contact bar, and to the steady state voltage across the field.

This bucking effect is proportioned to balance out under average conditions, both the opposing pull on the coil from the contact

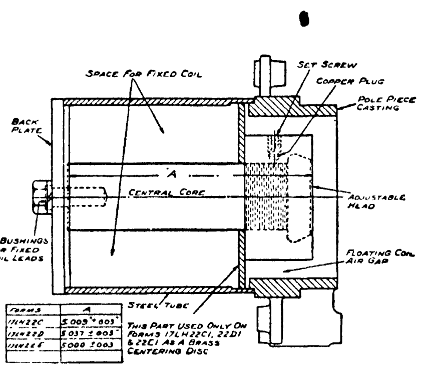


Fig. 31. Magnetic Structure of Voltage Control Relay for Auxiliary Generator

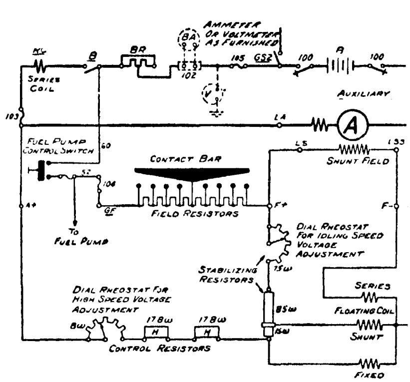


Fig. 32. Fundamental Connections of Voltage Control Relay

finger compression springs, and the steady state exchange current between the field and the coil through the stabilizing resistors.

Since the series winding is fixed, adjustment of compensation on individual relays is made by means of a second dial rheostat connected in the stabilizing circuit. This adjustment has the greatest effect at engine idling speed.

5. *Temperature Error.* Any increase in the voltage calibration value caused by the increase in fixed and floating coil resistance due to temperature, is nullified by the potentiometer action of the parallel connection of these coils. As the fixed coil resistance increases with temperature, an increased voltage is automatically provided for the floating coil, with resultant correct floating coil current irrespective of temperature.

6. *Counterweight.* The counterweight nullifies any effect on the floating coil from the motion of the locomotive. The lost motion provided within the counterweight imposes no appreciable restraint on any quick movement required of the floating coil, as during a sudden change in auxiliary generator speed or load.

REFERENCE DATA. Table 25 lists the cold and hot resistances of the relay coils and resistors. Shown also are the currents and voltages to be expected around the relay circuits at the normal generator speeds and loads. Intermediate values may be expected at intermediate speeds and loads.

ADJUSTMENTS. 1. Voltage Setting. For greatest accuracy, allow the relay coils to reach normal operating temperature before making adjustments.

Connect an accurate voltmeter across relay terminals A+ and A—. Operate the engine at top speed and adjust the right-hand dial rheostat for the desired voltage.

Next, operate the engine at normal idling speed and adjust the left-hand dial rheostat for the desired voltage.

Both rheostats can be set and locked in place by means of a screw driver inserted through the slots provided in the cover.

The normal voltage setting for a 32-cell lead battery is 74 to 76 volts, subject to modification under different service conditions. Refer to the battery manufacturer's instructions for details.

2. *Floating Coil Springs.* On relays built prior to Sept., 1940, the back spring only is adjustable. On relays built after Sept., 1940, the front spring only is adjustable. The setting should ordinarily not be disturbed. Should conditions result in insufficient range in the high-speed rheostat adjustment, or should the springs be disturbed during repairs, the correct setting is made as follows.

After the relay coils have warmed up, operate the engine at high speed. Position the high speed rheostat at the center of its travel. Remove the relay cover and adjust the front spring so that the desired voltage is held. Replace the cover and check the voltage, adjusting the high speed rheostat if necessary. Next, run the engine at idling speed and set the idling rheostat for the desired voltage.

The rear spring on relays built prior to Sept., 1940 is adjusted by turning the threaded spring rod, using a screw driver in the slot

in the end of the rod. Loosen the locknut before turning the rod.

The front spring on relays built after Sept., 1940 is swiveled at its upper end and threaded on the spring rod at the lower end. Loosen the locknut and revolve the spring on the rod to change the tension.

See Table 25, Column D, for the current to be expected in the floating coil shunt winding with the correct spring adjustment.

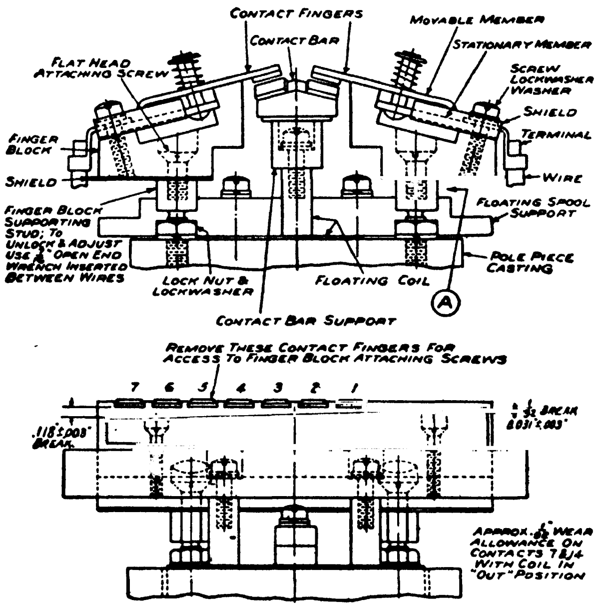


Fig. 33. Contact Details With Floating Coil at Inside End of Travel, Voltage Control Relay

3. *Stabilizing Resistor.* An adjustable contact clamp is provided on the blue enameled stabilizing resistor at the left of the operating mechanism. The positive side of the floating coil shunt winding is connected to this contact clamp. It should be set so that exactly 15-ohms are in circuit from the end of the unit.

4. *Magnetic Compensating Plug.* Differences in the magnetic circuits on individual relays are compensated for by means of a compensating plug screwed through the upper face of the floating coil. The plug was set and locked at the factory and should not be disturbed. In case of floating coil replacement, install the plug in exactly the same position in the new coil. If the plug is screwed

in too far, the relay will hold a low voltage at high speed, and some pumping action may result.

5. *Counterweight.* The counterweight drive is normally adjusted so that the weight is horizontal at the middle of its travel. Adjustment is made by screwing the ball bearing drive block up or down on the front spring rod with the drive pin removed.

6. *Contacts.* A slope is provided on the contact bar. This requires 0.084-in. floating coil travel to operate the 7 pairs of contacts. Additional travel of $\frac{1}{16}$-in. is provided, half of which is used for break at the inside contacts, and the other half for wear allowance at the outside contacts.

Inward coil travel is limited by the fixed internal floating coil stop. Outward travel is limited by the position of the finger blocks, the front floating coil finger supports stopping on the bottom of the blocks, point A in Fig. 33.

To check for proper travel and contact break, push the coil to its extreme "in" position, holding it there with a screw driver inserted at point A. Gauges of the thicknesses shown in Fig. 33 should slide in between the bar and each of the opposite end pairs of contacts.

To check for proper wear allowance, release the coil to its extreme "out" position and observe that the indicated wear allowance is obtained on each of the opposite outside pair of contacts.

The removable contact bar is fixed in position on its supports and is not adjustable.

Correction of travel, break and wear allowance is made by moving individual contact finger blocks in or out from the pole piece casting, by adjustment of the supporting studs. Blocks may be tilted slightly if necessary. See Fig. 33 for complete information.

Contact fingers are interchangeable. Note especially the order of assembly of the shield, finger, terminal, washer, lockwasher, and screw. Incorrect order of assembly will throw a contact finger out of line. Check each finger after installation for free hinge action.

Movė the floating coil slowly in and out by hand. Observe that the fingers on each block contact the bar in regular sequence. Note also that opposite pairs of fingers contact the bar at approximately the same time. Exact synchronism is unnecessary.

MAINTENANCE. 1. Contacts. The silver alloy contact material used on the bar and fingers is specially processed for long life and complete freedom from sticking. Good contact is obtained regardless of the degree of burning or blackening.

However, in time, sufficient material may transfer from a finger onto the bar, or vice versa, to upset the mechanical sequence in which the contacts make or break.

It is then desirable to remove the transferred material by a few strokes of a clean, fine file so as to restore the original surface. It is not necessary or desirable to file out the corresponding craters.

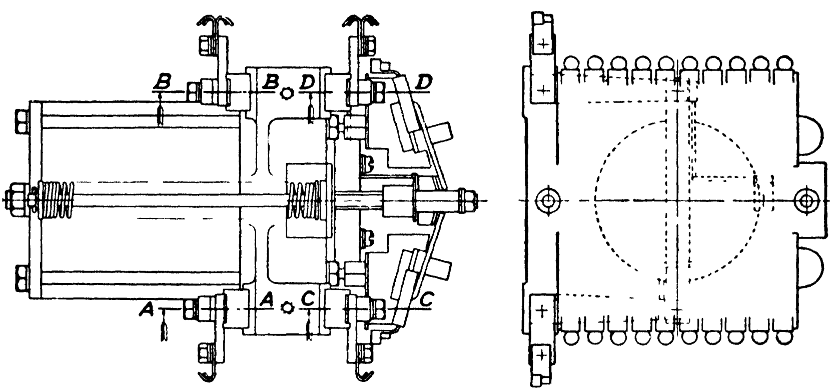


Fig. 34. Method of Assembly of Coil Supports for Voltage Control Relay, Type 17LH22C1

Never use abrasives, such as emery or carborundum, since the fine abrasive particles become imbedded in the silver alloy and interfere with the making of good contact.

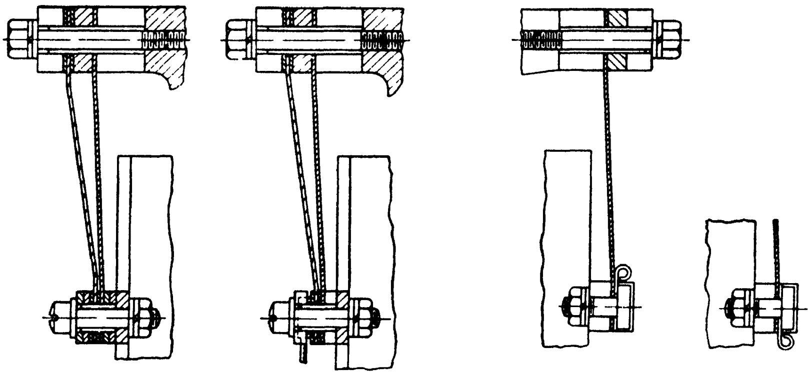
The transferred or built up material on the contact surfaces should normally be removed after each 1500-hours of operation, unless experience dictates otherwise.

Do not replace a contact finger without making certain that possible projections of built up material have been removed from the corresponding surfaces of the contact bar, to avoid improper sequence of contact operation.

When individual contact fingers show signs of severe burning or blackening, the reason should be determined and remedied. The most frequent causes are the failure of the adjacent contact finger

to make good contact with the bar due to imbedded foreign particles, excessive dirt or oil; or to a broken resistor connection.

When replacing the contact bar, make sure that the slope is



Section A-A Section B-B Section C-C Section D-D

Fig. 33. Coil Support Assembly

in the proper direction as indicated by the words "front" and "back" stamped on the ends of the bar.

After such removal of a bar or finger, check the sequence of the gaps as the floating coil moves in or out. See Fig. 31 for details.

2. *Floating Coil.* Check the floating coil at regular intervals for central location in its air gap. The normal clearance is approximately $\frac{1}{16}$-in. at all points. If this clearance appears to be appreciably less, the cause should be ascertained and correction made, to avoid possible error in the electrical setting. There should be no rubbing or friction in any moving part at any point in the normal travel. The floating coil springs should operate clear of all stationary parts.

Examine the spring steel supporting fingers and the flexible braided copper shunts for mechanical damage or possible corrosion.

Check the attaching screws at both ends of the supporting fingers for tightness.

3. *Counterweight.* Check the weight at regular intervals for absence of friction or binding, and see that the compression spring and spring post at the front of the brass block are in good order.

Check the ball bearing in the drive block. The bearing may be

TABLE 26. RESISTANCE DATA FOR VOLTAGE CONTROL RELAY RESISTOR UNIT

Section	No. of Turns†	Ohms	(Approx. Length)
A	8	13.35	0.0142″ Dia. x 8 Ft. 0″
B	6	10	0.0142″ Dia. x 8 Ft. 0″
C	7	7.35	0.0179″ Dia. x 4 Ft. 0″
D	8	5.44	0.0226″ Dia. x 4 Ft. 6″
E	9	3.87	0.0285″ Dia. x 6 Ft. 0″
F	11	2.97	0.036″ Dia. x 7 Ft. 0″
G	13	2.21	0.045″ Dia. x 8 Ft. 0″
H	21	17.8	0.0201″ Dia. x 11 Ft. 6″

†Material—Nickel Alloy GE Material No. B21C2A.

removed, if necessary, and the shields taken out for cleaning and lubricating. Use a high grade light oil. SAE-10-W used sparingly. Do not use grease.

4. *Coil Replacement.* It is advisable to remove the relay to a bench when replacing coils. Refer to Figs. 28, 29, 30, 31, and 32, for structural details. Figs. 34, and 35 show the order of assembly of the various parts in the floating coil supports.

To remove the fixed coil, disconnect the coil leads. Remove the counterweight drive pin. Removal of the two bottom square headed tie bolts will permit removal of the counterweight and its supporting bracket. Removal of the two top tie bolts will permit removal of the relay back plate, steel tube, central core and core head, and the fixed coil, all as a unit.

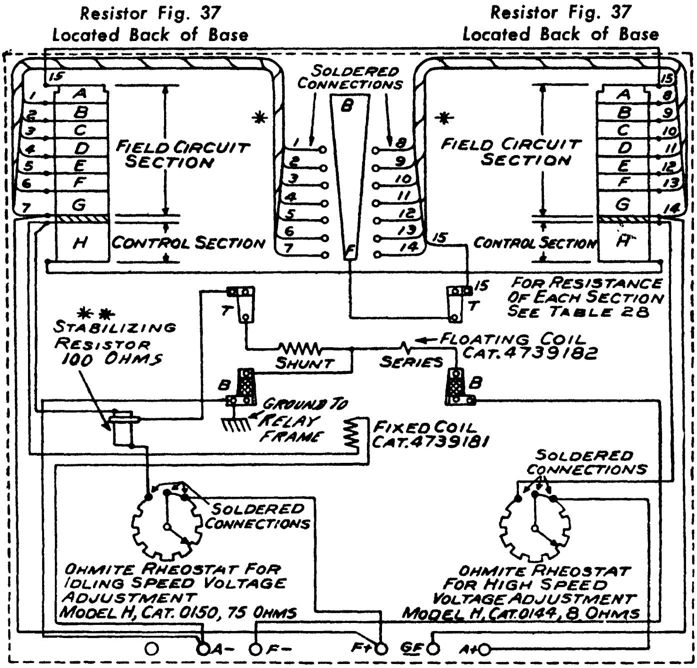
To remove the coil itself from this assembly, separate the back plate from the core by removing the attaching bolt.

A tab bent out from the fixed coil spool, engages in a hole in the back plate to prevent the coil from turning.

The core head is threaded on the core and was adjusted and locked at the factory in the best position for proper operation. Locking is by means of a hollow headed set screw and copper plug.

In case the core adjustment is disturbed, it should be reset at the dimensions shown in Fig. 31.

To remove the floating coil, first remove the counterweight and bracket, back plate, steel tube, central core and core head, and fixed coil as an assembly, as described above.



APPROXIMATE RESISTANCE (OHMS) OF EACH HALF OF RELAY RESISTOR UNIT, MEASURED BETWEEN CONTACT BAR & TERMINAL GF (OR F+) WITH EXTERNAL LEADS DISCONNECTED, AS SUCCESSIVE CONTACT FINGERS CLOSE ON THE CONTACT BAR

CONTACT FINGERS CLOSED	0	1 8	1 TO 2 8 TO 9	1 TO 3 8 TO 10	1 TO 4 8 TO 11	1 TO 5 8 TO 12	1 TO 6 8 TO 13	1 TO 7 8 TO 14			
OHMS	45.2	31.8	21.8	14.5	9.05	5.18	2.21	0			

FOR TOTAL RELAY RESISTANCE, MULTIPLY ABOVE VALUES BY 2.

COIL DATA			
CIRCUIT		CATALOG NO.	RES. AT 25°C.
FIXED COIL		4739181	10.15
FLOATING COIL	SHUNT	4739182	14.
	SERIES		0.245

Fig. 36. Connection Diagram for Voltage Control Relay, Type 17LH22C1

*Where cables pass through metal base, add supplementary insulation as follows: 2 wraps of ½ lap varnished cambric, 1 wrap of ½ lap friction tape, 1 wrap of thin fiber.

**QFK-5901208G2 in back of base on relays prior to July 1941 with compound base. QLK-5901245G2 in front of base on relays after July 1941 with metal base.

Next, remove both stationary contact finger blocks and the contact bar. Remove the contact bar support and disconnect the floating coil shunt winding lead. Remove the two screws which fasten the front cross support to the floating coil.

Remove the screws and hardware which fasten the stationary end of the bottom floating coil support fingers to the pole piece casting. The coil then can be removed from the pole piece casting as a unit.

The supporting fingers can then be removed from the coil. Note that the insulated connections are made through terminals and shunts which are soldered to the ends of the coil windings. These should be unsoldered and used again on the replacing coil.

Fig. 36 shows the internal relay connections.

Wheel Slipping Signal Relay—*WS1, WS2* (Type 17LV24E1) *Function.* These relays are connected to measure the difference in voltage between the traction motors in each truck. In the event either wheel slips, its motor voltage increases, while the voltage on the other motor decreases. This difference in voltage causes the relay to operate and energize the buzzer.

Description. This type of relay consists of an operating coil mounted upon an open type magnetic struncture and a hinged armature that protrudes into the center of the coil. The armature, which carries an adjustable core, has a contact arm which is arranged to make contact with either of two stationary contact studs. An adjustable armature spring is provided. Due to the small size and to the small movements involved, the power required for operating this type of relay is very small.

Operation. When the operating coil is de-energized the calibrating spring pulls the upper end of the armature inward and closes the back contact. When the operating coil is energized sufficiently to overcome the calibrating spring, the upper end of the armature is pulled outward and closes the front contact.

Adjustment. These relays are adjusted to pick up at 0.05 amp. and to drop out at approximately 90 per cent of pick-up.

The operation of these relays should be checked periodically. The pick-up setting can be changed by adjusting the tension of the calibrating spring, increasing it to raise the pick-up and decreasing it to lower the pick-up. The drop-out setting can be changed by adjusting the position of the movable core attached to the armature, screwing the core in to lower the drop-out and backing it out to raise the drop-out setting. The pick-up setting should always be

re-checked after changing the core position. After final settings are obtained make sure that the locknuts on the core and spring are properly tightened.

Inspection. These relays should be periodically inspected to insure that there are no loose or excessively worn parts and to insure that all moving parts are free from binding. A slight amount of play in the hinge pin bearing, both endwise and radially is permissible. Also see that the armature core moves freely in the opening in the operating coil.

The contact tips should have $\frac{1}{32}$-in. to $\frac{3}{64}$-in. gap and must be kept within these limits by adjusting the stationary contact tips.

The contact tips are made of tungsten and should seldom require any attention. If any roughness develops, the projections should be removed by drawing a fine file lightly across the surfaces. It is not necessary to file out depressed surfaces.

TABLE 27. TYPE 17LV24E1 RELAY DATA

1. Contact Data	
(a) Tip Gap	1/32 to 3/64-in.
2. Coil Data	
(a) Cat. No.	2738640
(b) Res. at 25 C.	525 ohms
(c) Pickup Current (set to)	0.05-amp.
(d) Drop-out Current	approx. 90% of pickup

Throttle Switches—101, 110 (Type PS-21) *Function.* The PS-21-D8 switch is arranged so that it will operate as soon as the throttle handle is moved from the idling position, thus furnishing an indication of the throttle handle position. Its contacts are connected in the main control circuit, closing this circuit whenever the throttle is moved out of the idling position, and opening it whenever the throttle is in the idling position, thus controlling all movements of the locomotive.

Operation. This switch is operated from the engine throttle control mechanism and when closed energizes the operating coils of the reverser, contactors, and the locking coil of the controller. Thus even though the controller be left in a running position, all power is removed from the locomotive whenever the throttle is moved to the idling position. Conversely, power can be applied to

the locomotive by opening the throttle, providing the controller has previously been placed in the desired operating position.

PS-21-D9 Switch. The PS-21-D9 switch, is also operated from the engine throttle control mechanism. This switch provides a reduced tractive effort step when the throttle is first opened. Its contacts close when the throttle is approximately quarter open, shorting out the part of the resistance in the exciter field circuit used to give this soft starting effect.

Description. This type of switch is of the magnetic quick acting

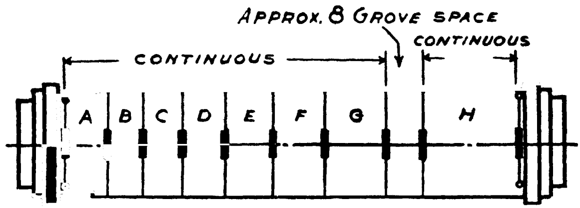


Fig. 37. Resistor Unit for Voltage Control Relay Located on Back of Base

spring return type. It consists of a spring operated contact arm with an auxiliary spring hinged armature and a magnetic series holding coil, all mounted on a suitable base. When the switch is operated, the spring contact arm closes the circuit through the series holding coil, the contact being made between the armature and the core of the holding coil. When opening the switch, the contacts are held closed by the series holding coil acting on the spring hinged armature until sufficient movement is made to take up all of the spring action, at which time the circuit is opened with a definite snap action.

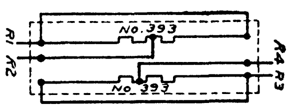
Inspection. The contacts are silver faced and should seldom require cleaning. If any cleaning becomes necessary, use a clean, lintless cloth wet with carbon tetrachloride or use a fine file. Do not use sandpaper or emery cloth as these materials will leave harmful grains in the contact surfaces.

TABLE 28. TYPE PS-21 SWITCH DATA

1. Coil Data PS-21-D8	PS-21-D9
(a) Cat. No. 4739178	4739179
(b) Res. at 25 C. 0.61 ohm	0.081 ohm

Push Button Control Switch—*117* (Type 17HP4L3) *Location and Function.* This switch is located at the operating position for controlling the various lighting and control circuits. The switch has a total of 13 individually fused circuits.

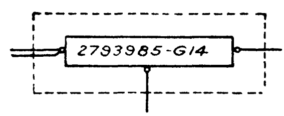
Operation. The control button energizes the main locomotive control circuit and in cases of emergency this one button can be opened to remove all power from the locomotive. The engine start button controls the engine starting contactors *GS1* and *GS2* which, when closed, connects the battery to the starting winding on the generator. The fuel pump button supplies power directly to the small fuel oil pump motor, this being operated from the control battery.



Misc. Parts	Box No.	
	1	
Catalog No.	Quantity	
2743999G3	2	
2743999G4	2	
1452059	4	

Fig. 38. Box No. 1 Field Shunting Resistor, Type 17EW102A2

May have to file contacts slightly on resistors in Box 4 in order to assemble in box. Approximate Resistance R1-R2 equals R3-R4 equals 0.01075-ohms.



Quant.	Part	Catalog No
1	Unit	2793985-G14
4	Terminals	4734358-G2

Fig. 39. Battery Charging Resistor Panel, Type CE-247-A

Approximate average resistance of each section equals 0.245-ohm.

The remaining buttons, except the bottom one, are used for lighting circuits. The details are shown on the locomotive connection diagram.

Inspection and Care. All of the circuits in both these switches carry control potential of 75 volts. Care should, therefore, be taken when removing fuses to see that the particular button controlling the circuit in which the fuse is located is in the open position.

The switches should be examined periodically for loose connections, broken parts and finger tension. The fingers and contact segments should be kept clean by wiping off occasionally with a dry cloth and then adding a thin film of light, high temperature grease, such as Stazrite No. 30 or equivalent. Both the fingers and

contact segments are renewable and should be replaced before the combined wear is sufficient to cause poor contact.

Resistors. *Type EW Resistors.* Various types of resistors are used for different circuits. Type EW resistors are furnished for the traction motor field shunting circuits. These resistors should be inspected periodically to insure that the tie rods holding the units in place are tight and that all connections are tight. The insulation between units should be kept clean at all times by blowing out with dry compressed air, being careful that the pressure is not too high.

Adjustable Resistors. Adjustable type resistors are provided for the ground relay, battery charging and for the exciter field circuits, these being furnished on Type CE-247 panels. These resistors should be inspected periodically to insure that the tie rods are tight and that all clips and terminals are tight. The resistor windings should also be inspected to see that they are not broken or nicked, or have any short circuited turns. Replace porcelain tubes if they are cracked or broken.

Vitreous Enameled Resistors. Several vitreous enameled resistor tubes are also provided for various circuits, these being mounted on Type 17FR7 panels. These resistors should be examined periodically to insure that all clips and terminals are tight and that the tubes have not been broken or damaged.

Values and Adjustments of Resistors. Refer to the Locomotive Wiring Diagram for resistor values and adjustments.

Instruments and Shunts (BA, 102, 112) *Location and Description.* The locomotive is equipped with a DO-40 type ammeter and suitable shunt respectively in the battery charging circuit. Some locomotives are equipped with a DO-58 ammeter and shunt in the return circuit for motors 1 and 2. The instruments operate on the D'Arsonval principle, using a permanent magnet for the field and a coil on the moving element for the armature.

Inspection. The instruments should be inspected periodically, while in position on the locomotive, to see that on each instrument:

1. Terminals are tight.
2. Pointer is on zero.
3. Pointer does not stick.

The pointers may be set on zero by turning the small screw

which is located on the front of the cover. This screw, by means of a small cam, changes the position of the metal piece to which the coil spring is attached, thus changing the tension on the spring and moving the zero position of the pointer accordingly.

The pointer may be tested for sticking by electrically obtaining maximum deflection and then noting results when the circuit is broken. If the pointer does not readily return to zero, the instrument should be removed for cleaning and calibration.

No attempt should be made to adjust or remove the instrument from the circuit unless it is certain that the current is off, as the terminals and the elements of the instrument are alive.

Shunts. Install shunts so that metallic dirt or dust cannot get on the resistance strip and short the shunts.

Keep terminals tight at all times.

Do not allow leads to become wet and thus shorted.

Ventilation. Although artificial ventilation is not required, the temperature rise may be from 40 to 50 C. (72-90 F.) above the ambient, and there should be enough natural ventilation to take care of this rise.

Cleaning and Repairing. We recommend that the instruments and shunts be returned to the General Electric Co., West Lynn, Mass., whenever cleaning, repairing or calibration becomes necessary.

Governor Solenoids—*113* (Type CR-9503-209C) *Function.* This solenoid, when energized, admits fuel oil to the engine through the governor. Automatic engine shutdown is obtained by means of a Detroit Lubricator pressure switch which opens the governor solenoid circuit when low lubricating oil pressure is obtained.

When de-energized the solenoid allows fuel oil pressure on the power piston to be equalized so that the spring forces the governor to the stop position, shutting down the engine.

Description. These solenoids are usually mounted on the apparatus which they operate. The end of the solenoid in which the plunger operates is always the bottom of the solenoid regardless of how the solenoid is mounted, and the opposite end is the top.

Cutout switches are mounted on the solenoids for d-c service to insert resistance in the coil circuit.

The following instructions should be followed if it is necessary to assemble or disassemble the solenoid.

Assembling and Disassembling (See Fig. 40). The solenoid consists of a frame 2, a plunger 6, a coil 3, two springs 4, two plunger guides 5, a cotter key 1, and, if required, a cutout switch. To disassemble, remove the plunger, cotter key, plunger guides, and coil springs, in the order named.

To assemble, put the coil in the frame, assemble the coil springs, and then the plunger guides. Fasten the guides with the cotter key.

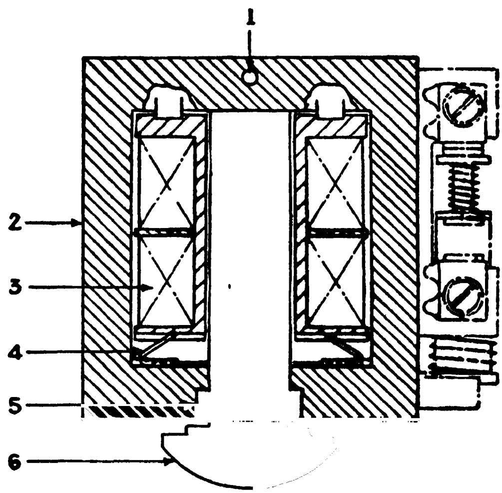


Fig. 40. Solenoid with Cutout Switch, Type CR-9503-209-C

If the solenoid is of the push-pull type, guides 5 and cotter key 1 are omitted.

Coils. Fig. 40 shows the normal position of the solenoid. When installing the coil make sure the projections are on top. The projections are used for centering the coil.

The end of the coil in which the plunger operates is always the bottom of the solenoid. It is very important that the coil is properly installed. If the coil is reversed the pull curve may be affected by this action.

Operation. On d-c circuits the coil when energized picks up the plunger and after the plunger seals, a resistor is inserted in series with the coil.

Series Holding Switch. Some single-unit locomotives are furnished with a series holding switch.

Function. This series holding switch holds the locomotive motors in series connection by preventing the series-paralleling contactor operations from taking place.

Whenever a heavy drag is started which would overload the generator with the motors in parallel, the engineman should see that the switch is thrown to the S position. This prevents the motor contactor sequence from proceeding beyond the series motor connections even though the master controller may be pushed into the series-parallel position.

Description. This switch is a two-pole manually operated tumbler switch without overload protection. The two normally open terminals are connected together thus giving a 4-point series break.

Operation. The switch is so placed in the control circuit that if it is thrown to the S position before the traction motor transfer and field shunting relay *V* picks up, it will serve to hold the locomotive motors in series connection even though the master controller handle may be advanced to the series-parallel position. This is accomplished by preventing the operating coil of relay *CR1* (in wires 2A and 65) from becoming energized, which in turn prevents the series-parallel contactor operating coils *SP1*, *SP2*, (in wires 2B, 2C, 65) from being energized because of a normally open interlock on *CR1* (wires 2 and 2A).

However, if the locomotive is operating in series-parallel connections and the current limit relay *CL* signal light indicates that an overload exists, the locomotive should be returned to series motor connections.

Throwing the series holding switch to the S position will not return the locomotive to series connections. The return to series connections must be accomplished by returning the master controller handle to the series position.

It should be remembered that the series holding switch is effective only before the traction motor transfer relay picks up. Throwing it to the S position after the transfer relay has picked up and with the controller handle in series-parallel position will not return the locomotive to series connections. The controller must be

used for backward transfer from series-parallel to series connections.

Control Equipment on 1000-Hp. Multiple Unit Locomotives. Control apparatus on the 1000-hp. multiple-unit locomotives which differs from that on the single unit locomotives, is covered by instructions on the following pages.

Master Controller (Type 17KC53A1) *Function.* The reverse handle of the controller controls the direction of motion of the locomotive.

The throttle (main lever), through the throttle operating mechanism, controls the speed of the Diesel engine.

Description. The fingers in this controller are of the hinged type, operated by means of moulded compound cams.

There are two levers; a main lever controlling the engine speed, and a reverse lever operating the two top cams. The main lever has an Off (idling) position, and eight operating points. The reverse lever has three positions; Forward, Off, and Reverse. It actuates the two top cams, which determine forward or reverse movement of the locomotive.

The reverse lever is interlocked with the main lever so it cannot be thrown from Forward or Reverse to the Off position, unless the main lever is off. The main lever cannot be turned on unless the reverse lever is in the Forward or Reverse position.

Inspection. 1. Check all moving parts to see that they operate freely.

2. Check the fingers for poor contact, burning and for proper wipe, break and pressure. Fingers should be replaced when worn down about half-way at the contact point.

TABLE 29. CONTACT DATA

Part	Min.	Max.
Wipe	1/8-in.	3/32-in.
Tip Gap	3/16-in.	1/4-in.
Pressure	3/4-lb.	1-lb.

3. Check all connections and terminals to insure good electric connections.

4. Apply a small amount of light grease to cams if necessary to reduce friction between cams and fingers.

Electro-Pneumatic Reverser (Type MC-57-E6) *Function.* The reverser changes the connections to the traction motor fields and thus reverses the direction in which motors will rotate.

Operation. It is operated by a double cylinder air engine controlled by two On type magnet valves. Their operation is dependent on the position of the controller reverse handle. The reverser is interlocked so that it cannot be operated except with the motor contactors open. As the reverser does not break any current, there should be no burning of the contacts. Any roughness that may develop due to other causes should be removed with a file.

Inspection. Frequent inspections should be made to guard against weak fingers, poor contacts and loose connections. The contacts should be cleaned when necessary and lubricated with a thin film of light, high temperature grease, such as No. 30 Stazrite or equivalent. The bearing grease cups should be kept filled with a good grade of cup grease and periodically tightened to insure that the bearings are properly lubricated.

The reverser should be tested for operation by pressing the valve pins in the top of the magnet valves. If the operation is sluggish and the segments and bearings are well lubricated, the cylinders and piston packings are probably dry and should be greased, using GE PC Control Lubricant No. 2 or equivalent.

Main and control contact fingers should be periodically inspected (and adjusted if necessary) to insure that the pressures are within the limits specified under Table 30, Contact Data. In all cases, it is necessary that a good contact be made between the fingers and segments. For adjustment of main fingers, refer to Fig. 20. About ⅛-in. wear is allowable on the main fingers while the control fingers should be replaced when worn half way through.

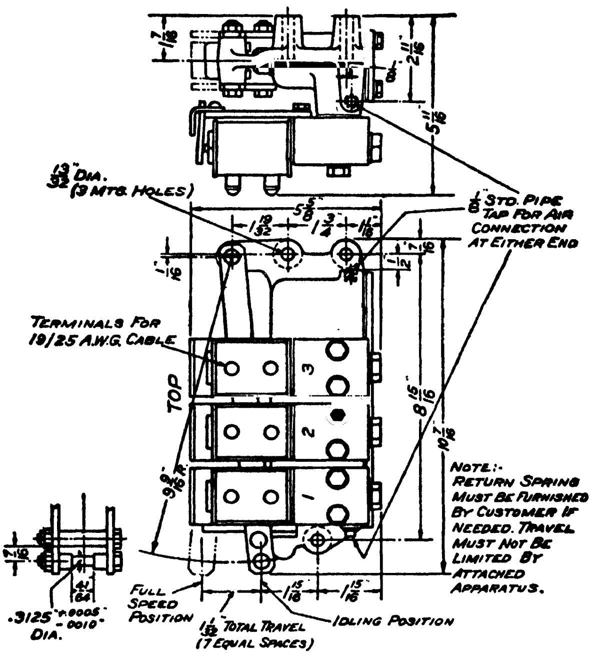
Sluggish action of the reverser may also be caused by sticky or leaky magnet valves.

TABLE 30. TYPE ME-57-E6 REVERSER DATA

1. Amperes continuous capacity (per motor circuit)	750 amp.
2. Contact pressure for individual main fingers	15 to 20-lb.
3. Contact pressure for control fingers	2 to 5-lb.
4. Magnet valve operating coil:	
(a) Catalog No.	3046106
(b) Ohms Resistance at 25 C	886

Refer to the Instructions on Magnet Valves for information on the valves used on this reverser.

Throttle Operating Mechanism (Type 17MK3L9) *Function.* A 17MK3L9 mechanism is mounted on each engine to operate its Woodward governor. The mechanisms operate in step under the



THE SUPPORTS OF THIS APPARATUS MAY BE GROUNDED.

Fig. 41. Outline, Operating Mechanism, Type 17MK3L

control of the master controller to control the speed of the Diesel engine.

Description. The mechanism consists of three small air cylinders and pistons actuating a lever attached to the Woodward governor. The governor is spring biased to its Closed or Stop position. The three pistons move the main lever by means of rollers and a system of inter-connecting levers and links so that the lever assumes seven definite progressive positions after leaving the Idle position as the air cylinders are energized in different combinations. The cylinders are supplied with air by individual 17MV23A4 magnet valves. As the three magnet valves are energized on successive

steps of the master controller, the lever progresses accordingly in seven approximately equal steps from idling to the full speed position. The full travel of the end of the lever from Idle to Full Speed is $1\frac{1}{32}$-in.

Inspection and Maintenance. See that all parts are free and that no air blows by the pistons or valves. Operate each valve by hand and see that each piston returns by itself when the valve is closed and the main lever held up out of the way.

When the pistons are removed for any reason the piston leathers should be greased with G-E PC Control Lubricant No. 2. If the leathers seem to need any lubrication during normal operation before they are taken apart, a small amount of G-E PC Control Lubricant No. 1 may be put in the oil holes in the top of the cylinders.

For care and adjustment of the magnet valves used on this mechanism, see the Instructions under Magnet Valves.

Sander Switch—*122* (Type 17HP9A1) *Location and Function.* This switch is located at the operating position for controlling the operation of the sander valves.

Description and Operation. It is a normally open, double contact, single circuit switch. It has silver-faced contacts and is mounted on a base of insulating compound. It is enclosed in a small metal case and is operated by depressing a foot button located in the cover.

Inspection. The switch should be periodically examined. The inspection should cover the following items:

1. Blow out all dust and grit with dry, compressed air.

2. Oil all bearings with a thin lubricating oil, such as G-E PC Control Lubricant No. 1.

3. Replace any broken springs or shunts.

4. Inspect cable inlets for wear and looseness. If necessary the cable should be taped in order to obtain a tight fit in the inlet openings.

5. Check all connections for cleanliness, and tighten connections if loose.

6. The silver contact surfaces should seldom require cleaning. Silver oxide is a good electrical conductor; hence no attempt should

be made to remove it. If any cleaning is necessary, use a cloth rather than a file or sandpaper as the latter will damage the contact surfaces and decrease their life. Contact parts should be replaced when the silver facing has worn through.

7. The contacts should be checked against the values given below.

TABLE 31. TYPE 17HP9A1 CONTACT DATA

Tip Gap	8/32 to 12/32-in.
Wipe	4/32 to 5/32-in.
Tip Pressure	1½ to 3-lb.

Series Holding Switch—*124 Function.* Some 1000 hp. multiple-unit locomotives are furnished with a series holding switch to hold the locomotive motors in series connection by preventing the series-paralleling contactor operations from taking place. This is true for both single-unit and multiple-unit operation.

Whenever a heavy drag is started which would overload the generator with the motors in parallel the engineman should throw this switch to the S position. This prevents the motor contactor sequence from proceeding beyond the series motor connections.

Return to Series Connection. If the current limit relay (*CL*) signal light indicates an overload on the generator, the series holding switch should be thrown to the S position, causing an instantaneous return to series connections. (**Note:** This is an open circuit transfer and probably will be quite rough unless the throttle is backed off somewhat before the switch is thrown.) The normal locomotive operation may then be continued with the throttle control until the drag conditions reach such a reduced point that you can go back to normal series-parallel operation, and at this time the switch may be thrown to the SP position.

Description. This switch is a two-pole manually operated tumbler switch without overload protection. The two normally open terminals are connected together thus giving a 4-point series break.

Operation. Throwing this switch to the S position energizes the *CR3* coil causing it to pick up and open the *CR3* interlock in series with the traction motor transfer and field shunting control relay contact *V* and the *CR1* interlock in wires 8R and 8J. With the

CR3 interlock open the series-parallel contactors, *SP1*, *SP2*, and the *CR1* control relay coil cannot be energized, thereby making it impossible for the motor contactor sequence to proceed beyond the series motor connections. It should be remembered that throwing the series holding switch to the S position while in series-parallel connection, causes an instantaneous return to series connections.

Control Relays—*CR2*, *CR3* (Type 17LV40D6). The *CR2* relay performs the same function that the *PS-21-D9* switch *110* does on the single-unit locomotives. It provides a reduced tractive effort step when the throttle is first opened.

The *CR3* relay prevents transfer of the motor circuits from series to series-parallel when the series holding switch is in the S position.

For maintenance and adjustments, see Instructions on the *CR1* relay which is identical.

Locomotive Connection Diagram Circuit Analysis. A brief description will be given below of each of the main sections of the wiring before going through the actual controlling circuits which the engineman directly operates.

Sections referred to will be found on the locomotive connection diagram. All circuits on the diagram are shown in the de-energized position.

Main Motor Circuits (See Sections E and F). Refer to Fig. 42. This circuit feeds four traction motors from a single main generator G. The motors are arranged for series and series-parallel connection, with a field shunting connection in series-parallel.

When starting in series the circuit is from the generator *GA* lead through motor 4 armature, motor 3 armature, reverser, motor 4 field, motor 3 field, reverser; through contactor S, motor 2 armature, motor 1 armature, reverser, fields 2 and 1, reverser, exciter differential field and back to generator *GAA* terminal.

When transfer takes place a few incidental things happen which will be explained later. So far as the motor circuits are concerned, contactor *SP1* picks up, so the current flows through motors 4 and 3 and right back to the generator. Motors 1 and 2 are short circuited. Then contactor S opens and removes the connection between motor 3 and motor 2, after which *SP2* picks up. This gives the series-

parallel connection, half the generator current flowing through motors 4 and 3, and the other half through motors 2 and 1.

When contactors M1 and M2 pick up, some current is shunted out of the motor fields and gives an increase in motor speed.

To reverse direction, the reverser throws over and reverses the order in which the current flows through the motor fields.

Wheel Slip Circuits (See Sections B and F). Refer to Fig. 42. A resistor *WSR1* or *WSR2* is connected across each pair of motor armatures, and a relay WS1 or WS2 between the mid-point of the armatures and the mid-point of the resistor. So long as no slipping occurs, these two points are at the same potential and no current flows through the relay. If slipping occurs this voltage balance is upset, and the relay picks up, its contacts (between 50 and 50A wires) causing the slip relay buzzer to operate.

Current Limit Signal Relay Circuits (See Sections B and F) Refer to Fig. 42. A current limit signal relay is in series with motors 4 and 3 through the SP1 contacts J1-J2. Whenever the load in this circuit exceeds 700-amp. on the 660-hp. locomotive or 900-amp. on the 1000-hp. locomotive, the relay will pick up and its contacts 50-50B will light the indicating light warning that the equipment is being overloaded.

Ground Relay Circuits (See Sections C and F) Refer to Fig. 42. A ground relay GR in series with some resistance *GRR* and the 108 cut-out switch is connected between the J3 reverser lead and ground. Since this is the only normal ground connection, there should be nothing but a slight leakage current in the ground relay. If an abnormal ground occurs elsewhere in the circuits, there will be a voltage difference between ground and the *J3* lead, and current will flow through the ground relay. It will pick up, and its contacts *8A-8H*, and *8F-8G* will open the exciter *EF* and generator field *GF* contactors and promptly kill all voltage. If no trouble can be detected by sight or smell, it may be that the ground that has occurred would not prevent operating safely. If the relay opens twice, and no indication of real trouble is found, the cut-out switch 108 may be opened, and operation may be found possible.

Transfer Relay Circuits (See Sections C and E). Refer to Fig. 42. The V relay has a series and a shunt coil. The series coil is con-

nected with the *VR7* resistor across the generator commutating and exciter differential fields, and therefore, responds to generator current. The shunt coil is connected through resistance across the generator voltage. *VR1* resistor is the one which determines the normal relay pick-up. *VR2* and *VR3* are cut in during field shunting, to raise the relay drop-out to a point where the motors will unshunt before overloading the generator. *VR4, VR5, VR6* are cut in momentarily during transfer from series-parallel to parallel to ensure the relay dropping out during transfer, so field shunting will not immediately follow.

By working on a combination of generator volts and amperes, the relay is enabled to work at any throttle position when proper conditions exist.

Excitation Circuits (See Section E). Refer to Fig. 42. The exciter field is doubly fed. It gets some self-excitation from its own voltage from *EA* terminal and wire *R5*, through some resistance, to field on wire *R6* and back to the exciter terminal *EAA*. It also gets separate excitation from the battery through contactor *EF*, a single tube "soft start" resistor (not on some 660-hp. locomotives), some more resistance, thence to the exciter field and back to the battery. The soft start section is cut out by a throttle switch 110 (relay *CR2* on multiple unit equipments) at about ¼ throttle. The exciter armature then feeds the generator field through contactor *GF*, across whose contacts a discharge resistor is connected.

Battery Charging Circuits (See Sections A, B and D). Refer to Fig. 42. When the auxiliary generator is started and builds up voltage, the *RC* relay picks up and closes *B* contactor. This makes a circuit from terminal LA through fuse 103, *RC* series coil, contactor *B*, battery charging resistor BR, ammeter shunt 102, battery fuse 105 and switch 100 to the battery and back through the other pole of the switch to the auxiliary generator. When shutting down, the generator voltage drops, and as soon as the battery starts to send current backward into the generator, the *RC* series coil causes this relay to drop out and open contactor *B.*

The auxiliary generator field is fed from the fuel pump wire 52 through the voltage regulator. The field circuit is primarily through the resistor controlled by the tapered bar, and the regulating

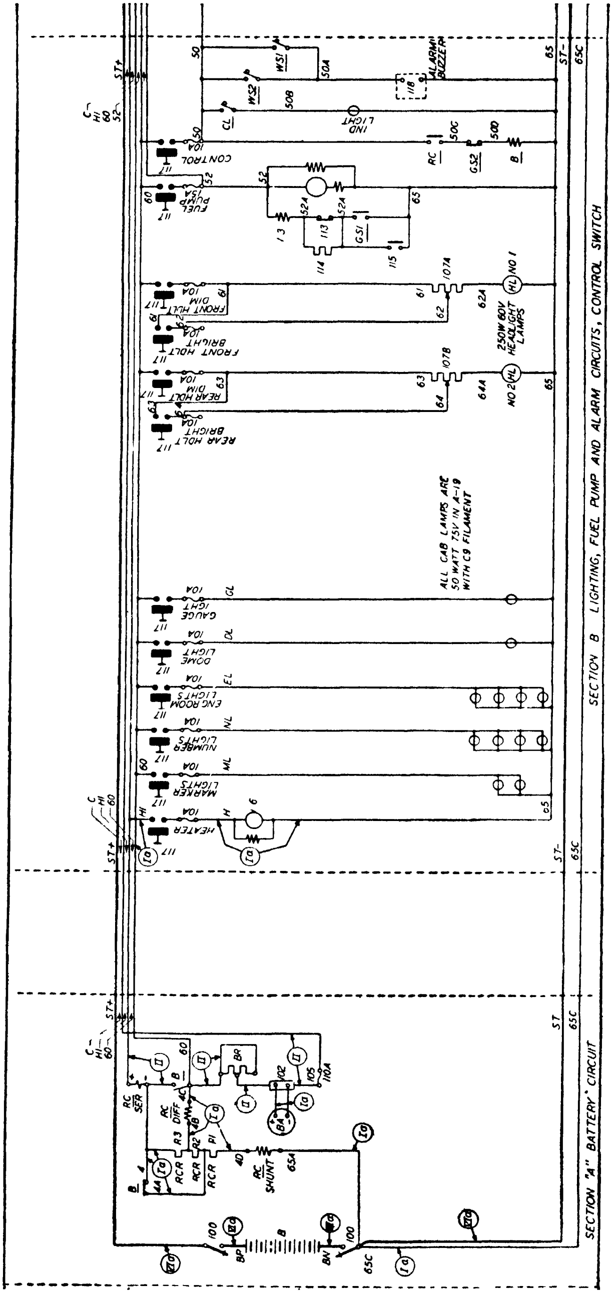

SECTION B LIGHTING, FUEL PUMP AND ALARM CIRCUITS, CONTROL SWITCH
SECTION "A" BATTERY CIRCUIT
ALL CAB LAMPS ARE 50 WATT 75V IN A-19 WITH C9 FILAMENT
250W 60V HEADLIGHT LAMPS
ALARM BUZZER
IND LIGHT
CONTROL
FUEL PUMP
FRONT HDLT DIM
FRONT HDLT BRIGHT
REAR HDLT DIM
REAR HDLT BRIGHT
GAUGE LIGHT
DOME LIGHT
ENG ROOM LIGHTS
NUMBER LIGHTS
MARKER LIGHTS
HEATER
RC SER
RC DIFF
RC SHUNT

Fig. 42

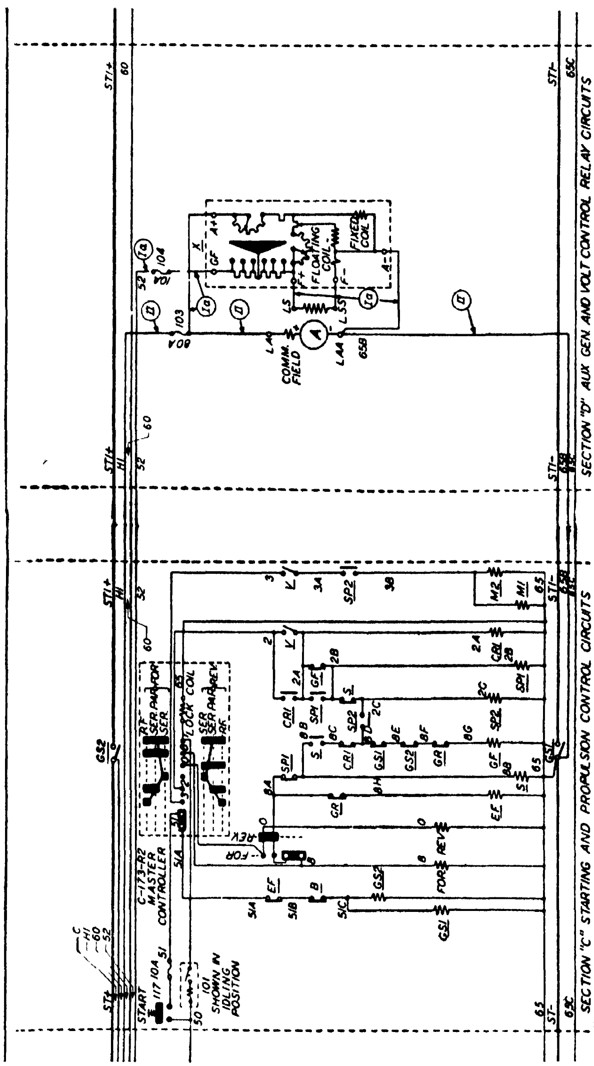


Fig. 42—Continued

circuit through the high-speed dial rheostat at the A+ lead to the fixed and floating coils. The low-speed dial rheostat, or wiggle resistor, which connects these two circuits is to prevent hunting. The small section of floating coil in the field circuit prevents holding different voltages at idling and top speed, and compensates for varying spring pressure as the tapered bar brings more or less fingers in contact. An increase in voltage causes the bar to cut in resistance to stop the rise, and a fall in voltage shorts out resistance.

The power comes from the 52 wire, both so it can be removed without adding an extra contactor to the circuits, and also so the fuel pump motor may serve as a discharge resistor for the field when the circuit is opened.

Control Circuits—General. After closing the main battery switch 100, the engine may be started. This is done by pressing the control, fuel pump and engine start buttons. Wire 60 comes from the battery, and energizes wire 52 through the fuel pump button, thereby starting the fuel pump. It also energizes wire 50 through the control button, which goes through the engine start button to wire 51. The controller must be off, so wire 51 can feed through to wire 51A, which then goes through *EF* and *B* interlocks to pick up *GS1* and *GS2* starting contactors.

An interlock on *GS1* makes a circuit from wire 52 through the governor solenoid 113. This solenoid picks up through its own interlock, which then cuts in the 114 resistance to protect the coil. Wire 52 also energizes the auxiliary generator field through the regulator.

GS1 and *GS2* main contacts connect the battery to the main generator and its starting field. The generator then acts as a motor to crank the engine. When the engine fires and builds up oil pressure, contact 115 closes so the governor solenoid will remain energized when the starting button is released and the *GS1* interlock opens. Thereafter a loss of oil pressure will drop 115 and kill the governor solenoid, and stop the engine. Pulling the fuel pump button will have the same effect, as well as stopping the fuel pump and killing the auxiliary generator field.

As the voltage builds up on the auxiliary generator, the reverse current relay *RC* will pick up, and its contact will pick up charging

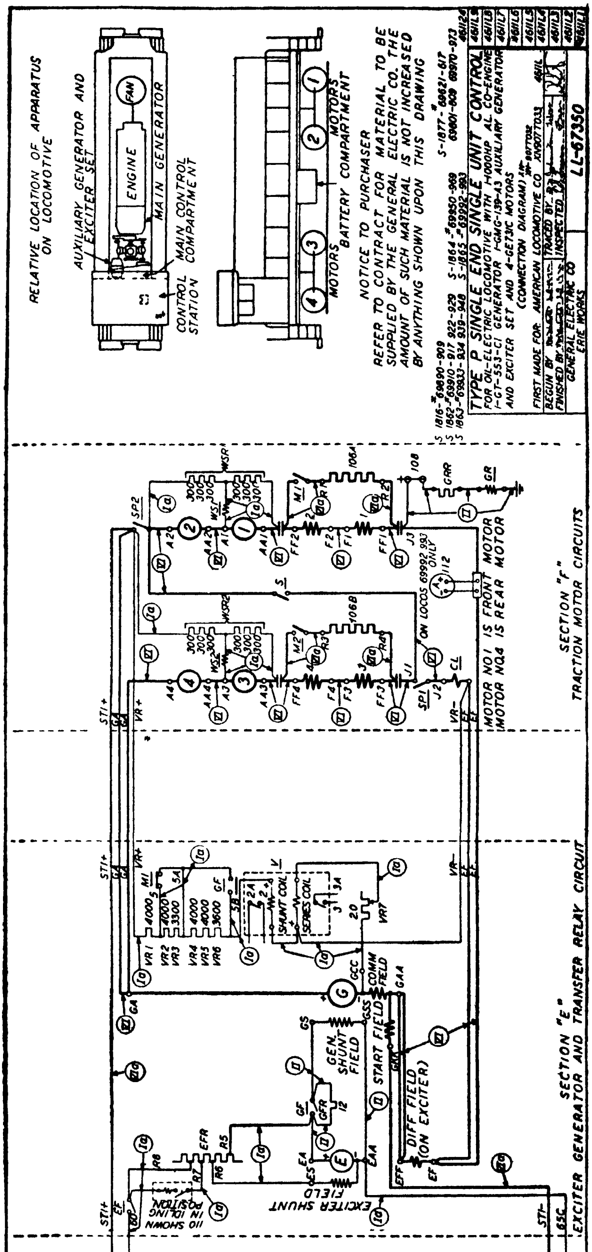


Fig. 42—Continued

contactor *B* if the engine start button has been released. *B* contactor interlock 51B-51C will then lock out the engine starting contactors *GS1* and *GS2* if the engine start button is later accidentally pressed. Charging current will show on the battery ammeter. The locomotive is now ready to operate.

On the standard single unit equipment, the reverse handle is then thrown forward or reverse, to determine direction. Usually it will be thrown clear through to the R.F. (reduced field or field shunt) position.

Now when the throttle is opened, switch 101 closes energizing wire 1. This picks up a lock coil which prevents reversing the controller until the throttle is closed again. It also energizes wire 8 if set for forward motion, or wire 0 if set for reverse, and also wires 2 and 3 if the handle has been thrown clear through.

Wire 8 (or 0) energizes the proper reverser coil, and only after the reverser is thrown properly feeds through the reverser interlock to wire 8A. This picks up *EF* contactor, the *S* contactor, and an interlock on the latter picks up *GF*. *EF* causes the exciter to generate voltage, *S* connects the motors in series, and *GF* then causes the generator to apply voltage to the motors.

The throttle may then be opened farther to increase the locomotive speed. At about ¼ opening it closes switch 110 which cuts out the soft starting resistor (if so equipped).

At some point the transfer relay *V* will pick up. This relay's contacts are in the No. 2 and 3 wires. If the controller is set in series, nothing will happen as these wires are dead. If in series-parallel or R.F., there will be a circuit from wire 2 through *V* relay contact to wire 2A to pick up *CR1* relay,, which starts the transfer to series-parallel. No circuit will be made from the No. 3 wire through the other contact as *SP2* interlock is open.

CR1 closes contact 2-2A which makes a holding circuit to hold the series-parallel connections after *V* relay drops out later. Its 8C-8D contact opens and drops out *GF* contactor. This starts the generator voltage dropping. An interlock 5A-5B also cuts *VR4-VR5-VR6* resistors into the transfer relay shunt coil to ensure further that the relay will drop out during the transfer. Another interlock 2A-2B on *GF* closes and picks up *SP1*, short circuiting motors 1 and 2.

An *SP1* interlock 2A and 2B closes to make a holding circuit to keep the series-parallel contactors up after *GF* picks up again later. Another interlock 8A-8B opens and drops out *S*, disconnecting motors 1 and 2 from motor 3.

A 2B-2C interlock on *S* closes and picks up *SP2*, putting motors 1 and 2 back on the line. Prior to this point the *V* relay has dropped out again, so the 3A-3B interlock on *SP2* does not pick up *M1* and *M2*. The 2C-8D interlock closes and picks up *GF* again. This restores voltage to the motor circuits, and the 5A-5B interlock on *GF* restores the *V* relay coil to its original pick-up setting.

The motors are now in series-parallel, and the generator will automatically set itself at about half the volts and twice the current that existed before transfer.

When the locomotive speeds up further, the *V* relay will pick up again. If the controller is in the series-parallel position, nothing will happen; but if it has been thrown clear through to the reduced-field position, then there will be a circuit from wire 3 through the relay contact to 3A, through *SP2* interlock which is now closed, and *M1* and *M2* will pick up, giving field shunting operation. An interlock on *M1* cuts in *VR2* and *VR3* resistors thereby resetting the *V* relay drop-out.

If the *V* relay later drops out the field shunting will be lost. The motors may also be returned to regular series-parallel by pushing the controller back to the series-parallel position, which will de-energize wire No. 3.

The controller may also be pushed back to series, killing wire 2. This will cause *SP1*, *SP2*, *CR1* and *GF* all to drop out. After *SP1* drops, *S* will pick up, and then *GF* will pick up again. This puts the motors back in the series connection. All power is removed in the process, and a smoother transfer back to series will be made by partially closing the throttle before pushing the controller back. It is also possible, and usually preferable, to shut the throttle clear off and come on again. This always brings the motors in series, and the controller may be set in series if it is desired to hold them there positively.

Multiple Unit Locomotives. A few variations of the above apply to switchers equipped for multiple unit operation.

Instead of a selective reversing controller and a throttle, these locomotives use a master controller with a small reversing handle, and a main handle giving eight running notches. Instead of a throttle controlling engine speed mechanically, the controller main handle actuates electro-pneumatic valves on an operating mechanism connected to the governor. Multiple unit sanding is also provided, and a means of lighting the rear headlight on the rear locomotive from the engineman's position on the front locomotive.

An extra motor control button is provided on the BS switch. With the controller reverse handle off, it is not possible to move the main handle, to speed up the engines for testing or pumping air, as is readily done on the single unit equipment. To do this on M.U. equipments, open the motor control button, throw the reverse handle in either direction, and then pull out the throttle. At all other times, the motor control button is left closed.

The engines are started exactly as on single unit locomotives.

To operate, throw the reverse handle in the desired direction, and open the throttle one notch. Wire 50 is thereby connected to 5A, and through the motor control button to wire 5, which feeds the reverse drum and the 8 and 0 wires, respectively, according to the direction of travel.

Wire 50 also energizes wires 1, 2, 3, and 4 on various notches. These wires control soft start and engine speed.

On notch 1, none of these are energized, and the engine runs at the same speed as at idling.

On notch 2, wire 1 picks up *T1* valve to increase engine speed.

On notch 3, wire 2 picks up *T2* valve to increase engine speed. Wire 4 is also energized, picking up relay *CR2* on both locomotives, and cutting out the soft starting resistor.

On notch 4, wires 1 and 2 pick up both *T1* and *T2* to increase engine speed.

On notch 5, wire 3 picks up valve *T3* to increase engine speed.

On notch 6, *T1* and *T3* are both energized.

On notch 7, *T2* and *T3* are both energized.

On notch 8, *T1*, *T2*, and *T3* are all energized, giving maximum engine speed.

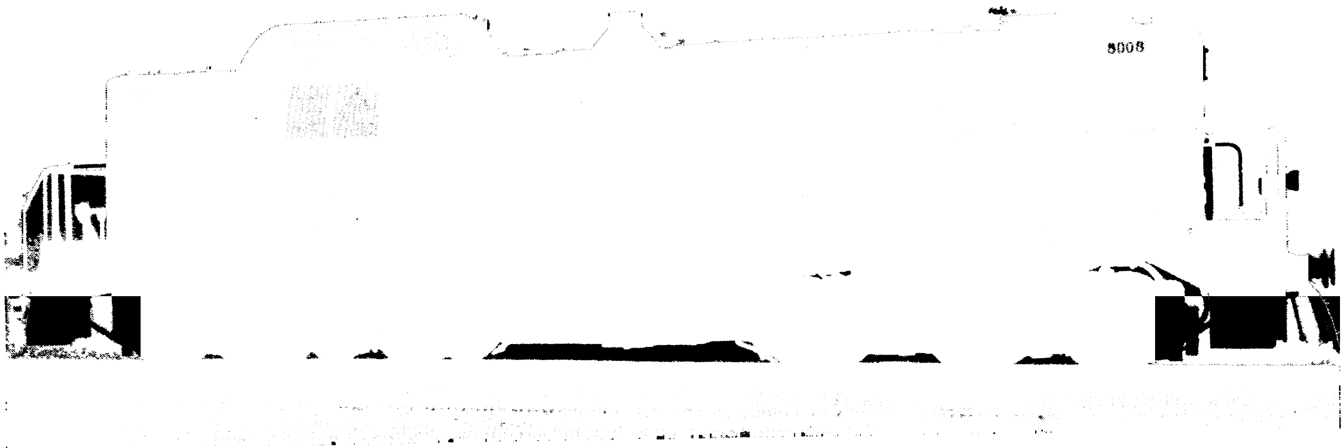
On any of these notches, wire 8 (or 0) establishes the series

motor connection, and transfers the motors to parallel and to field shunting when the V relay operates exactly as on single unit equipments. The difference is only that there is no means on the controller of preventing these transfers, so a relay CR3 and a tumbler switch has been added. The tumbler switch is usually left open. When closed it picks up CR3 on both locomotives, and the 8A-8R contact on CR3 prevents the parallel contactors and relay CR1 from picking up. This switch may therefore be used to hold the motors in series, or to transfer back to series if already in series-parallel. There is no way to permit series-parallel operation but still prevent field shunting.

Extra interlock fingers are placed on the reverser to determine what sander will be actuated electrically. Pressing the sander button will always give sand on both locomotives for the direction which they are set to move, regardless of the ends which may be coupled together.

Headlight Control. To operate the front or rear headlight, the proper dim button must always be in. If the bright button is also in, some resistance is short circuited and the lamp will burn at full brilliancy.

On multiple unit jobs, a third pair of buttons controls the headlight on the other locomotive which is farthest from the operator, regardless of how the locomotives may be coupled together.



1000 Horsepower Alco Road Locomotive

Chapter X

Alco–GE Diesel Electric Road Locomotive 2000 Hp. Equipment

A. GENERAL DESCRIPTION

"A" Lead Unit. The electrical equipment for the No. 2 Diesel engine is in general similar to the equipment for the No. 1 Diesel engine. The identification symbols for the No. 1 engine transmission are noted by letters and single digit numerical symbols, whereas the transmission units for the second engine are denoted by the same letters and double digit symbols. For instance, the generator in the No. 1 power plant is symbolized by *G1* and the No. 2 power plant generator is *G2;* No. 1 power plant contactors *P1, P2* and No. 2 power plant contactors *P21* and *P22* and so forth.

"B" Booster Unit. The electrical equipment on the *B* unit is practically a duplicate of the electrical equipment on the *A* unit. Therefore, for information about the *B* unit electrical equipment, look for the same headings under the description of the electrical equipment paragraphs.

Transmission of power from Diesel Engine to Wheels. There are three fundamental parts to the Diesel locomotive power system. They are the Diesel engine, the generator, and the traction motors. The Diesel engine drives the generator, the generator produces electrical power which drives the traction motors. Each traction motor is connected to an axle through a pinion and gear. There are two traction motors for each power plant or four per locomotive unit.

Opening of Throttle. When the throttle is opened to the first notch, the 75-volt control wires are energized and act to throw the reversers, in the contactor cabinet, tò the proper direction and close the main power switches which connect the generators to the traction motors. Simultaneously the generator field switches are closed. The generator fields are thus excited, the generators develop electric power, and the locomotive starts to move.

Opening the throttle to successive notches changes the setting of the Woodward governor through the throttle operating mechanism. This raises the engine regulating speed of the governor. Therefore the Diesel engine will be speeded up through the admission of more fuel to the engine by the fuel injection pump control rods which are opened up by the governor. The Diesel engine will increase its speed until the new speed setting of the governor is reached. As the throttle is opened to successive notches, the process is repeated on up to 740 r.p.m., the top speed of the engine. As the engine runs faster, more power is delivered to the generator and thus to the traction motors.

Engine Output. Power regulation to maintain constant engine speed and horsepower, is accomplished by the use of a separate exciter which excites the main generator field. The exciter controls the field in such a way as to always make the generator draw full power out of the engine in the last or eighth notch, regardless of the electrical effects of the traction motors upon it. Traction motor current and voltage vary automatically with changing locomotive speed.

Transfer of Motor Connections. As the locomotive speed increases, traction motor current will decrease and voltage will increase. To control the voltage and current relations between the generator and traction motors, three different sets of motor connections are used. These connections are as follows:

1. *Series*—low to intermediate locomotive speeds.
2. *Parallel*—intermediate to medium high speeds.
3. *Field Shunting*—motors in parallel with shunted or reduced traction motor field current—medium high to high locomotive speeds.

In *Series* connection the current from the generator goes directly through one traction motor then through the second traction motor and back to the generator to complete the circuit.

In *Parallel* the generator current is split, half of it going through one traction motor and half through the second motor, wires returning from each motor to the generator to complete the circuit.

In *Field Shunting* connection a portion of the traction motor field current is by-passed through an electrical resistance, with the main connections still in parallel.

Each one of the above steps will increase the generator current and reduce the generator voltage to keep the equipment within its operating range as the locomotive speed increases.

Low Voltage Circuit. The main parts of the low voltage circuit are the auxiliary generator, the batteries, and various control contactors and relays. The batteries are used to start the Diesel engines and furnish standby power for control and lighting circuits. After the engines are started the batteries have no function except to be charged by the auxiliary generators.

The auxiliary generators furnish low voltage electricity for all the locomotive auxiliaries; such as lights, fuel pump motors, and the boiler. They furnish power to energize or close all the main power switches and relays. They also furnish a portion of the main generator exciter field current and power to charge the batteries.

B. PROPULSION EQUIPMENT

Main Generator G1, G2. The main generator armature is direct connected to the Diesel engine and rotates in a counterclockwise direction looking at its commutator end. The generator frame is bolted to the engine structure and the generator feet are set on springs to take a portion of the overhung weight.

The commutator end frame head encloses a single main generator self-aligning bearing and the other end of the armature is rigidly connected to the engine crankshaft: The generator is self-ventilated by a fan on the engine end of the armature.

Main field excitation is supplied by a separate belt-driven exciter which governs the output characteristic of the generator. A starting field for cranking the engine is built in with the main field of the generator.

Auxiliary Generator A1, A2. The auxiliary generator supplies power for all low voltage circuits and for charging the locomotive storage battery. The armature is overhung on the main generator shaft extension by means of a tapered fit and the auxiliary generator frame is fastened to the main generator frame head.

The field is self-excited and is externally controlled by an automatic voltage regulator.

Exciter E1 or E2. The separate exciter, which supplies excita-

tion to the main generator field, is a self-contained unit mounted on top of the auxiliary generator and is belt-driven from the main generator armature shaft. The exciter is of the two-bearing type with a pulley on the shaft extension.

This machine is ventilated by a fan mounted on the armature.

The exciter field poles are split in two sections and excited by shunt and differential windings. The differential winding is connected in series with the main traction circuit. The combined effect of the shunt and differential windings results in the combined generator exciter unit delivering its designed output.

Field Control or Speed Switch 104A, 104B. This switch is an automatic auxiliary regulating device applied to the generator field circuits so that the generator will load the engine to maintain constant engine speed, in the event of any unusual loading condition. It functions only in the last operating notch.

The speed switch varies the resistance in series with the field of its respective exciter at predetermined speeds of rotation. It is cut into the circuit only on the 8th throttle notch, by means of relay *CR2*.

The switch has but three leads leaving the housing. These are marked *C*, *1*, and *2*. The circuit between all three leads is normally open, but as the speed of rotation increases to that at which the switch is set to function, the circuits between *1-C* and *2-C* open and close at least once every revolution within an approximated range of speed of from 730 to 735 r.p.m. and will close fully at 735 r.p.m.

The main parts of the rotor are: a hub casting, a spring returned weight, three slip rings and two contact fingers. The hub is designed for mounting on the exciter shaft extension and it supports the three slip rings, also the hinged weight. The slip rings are insulated from the hub and also from each other by the tube and spool method.

Direct Current Traction Motors 1, 2, 3, 4. Each direct current traction motor is of the box frame type carried on the trucks through two axle bearings and a spring nose support located on the truck bolster. Each motor has two grease lubricated roller bearings on its armature shaft. The axle bearings are waste packed and of the constant oil level type.

Each motor is pressure ventilated from belt-driven blowers

located in the engine room. The gear case enclosing the motor pinion and axle gear is bolted to the motor frame.

C. CONTROL EQUIPMENT

Master Controller. The purpose of this controller is to control the speed of the locomotive and to fix its direction of motion.

The controller has two handles: the throttle and the reverse handle. It also has a number of cam-operated hinged type contacts which are connected in the control circuits. At the top of the controller is a notched ring segment against which presses a pawl. The arrangement is such that the throttle must be notched slowly from one position to another.

The throttle and the reverse handle are so interlocked that the reverse handle is removable in the *neutral* position only when the throttle is in the *off* or *idling* position. When the reverse handle is removed, the throttle cannot be moved from the *idling* position. The mechanical interlocking also prevents moving the reverse handle into or out of the *off* position unless the throttle is in the *idling* position.

With the reverse handle in place, it is possible to move the throttle to any position. Thus, with the reverse handle in the *off* or *neutral* position, the throttle may be moved to any position for engine testing purposes.

Master Controller *B* Unit. The purpose of this controller is to fix the direction of motion and speed of the booster unit when it is being operated alone.

The controller has a throttle lever and a reverse handle. It also has a number of operated hinged type fingers which are connected in the control circuits. The mechanical interlocking of the throttle and reverse levers is the same as for the *A* unit except that when the reverse lever is either removed or in the *off* position, the throttle cannot be moved from the *idling* position.

Multiple Unit Operation. In multiple unit operation the *B* unit is connected to *A* unit and the *A* unit controls operation of both units. The throttle on the *B* unit master controller is moved to the *idling* position and its reverse lever removed from the controller. This is to prevent unauthorized movement of the operating lever when the units are controlled from the head end of the *A* unit.

During multiple unit operation the action of the reversers, contactors and motors is controlled entirely from the master controller in the *A* unit.

Push Button Control Switches. Push button control switches are located at the engineer's operating position for controlling various lighting and control circuits. One switch is used for controlling lighting circuits and the others are used for the various main control circuits and for attendant calls. The switch for the main control circuits is also provided with a lock at the top of the switch. Before operating any of the buttons, insert the key and turn it to the running position. Since the key is removable in the locked position, no operation of the locomotive can be obtained unless the key is in place. Only one key is provided, thereby making it impossible for anyone except the proper authorized person to operate the locomotive.

Another push button control box is located at each engine control station. Each box has a fuel pump switch, engine starting switch, and engine control or isolation switch. There are four individually fused circuits in the box, two of the circuits being operated by the engine start button.

These switches handle all of the 75-volt control circuits. Care should, therefore, be taken when removing fuses to see that the particular button controlling the circuit in which the fuse is located is in the open position.

Isolation Switches and Engine Control Buttons. The third button on the control box at each engine control station is marked Engine No. 1 or Engine No. 2. Its purpose is to enable the operator to isolate one of the power plants in case of trouble. When the button is pulled out the *EV* magnet coil is de-energized and the main generator field circuit is held open through an interlock on the oil pressure relay. Thus the engine will not run at any speed except idling, and no power can be transmitted from the generator to the traction motors.

Magnet Valves. The magnet valves which are used to actuate the motor reverser, the governor operating mechanism, the engine control, and the air-operated contactors, are all of the so-called *ON* type. Some have enclosed coils and some have open coils. The *ON*

type magnet valve is of the double acting type and has an inlet and an exhaust port as well as a port for connecting to the operating cylinder. This valve is so constructed that when the coil is energized the exhaust port is closed and the inlet port opened, thus admitting air from the reservoir to the operating cylinder. When the coil is de-energized the inlet port is closed and the exhaust port is opened and thus connects the cylinder to atmosphere.

Interlocks. Electrical interlocks are provided for most of the electro-pneumatic and magnetic contactors, relays, and the reversers. The interlocks are connected in the circuits of the operating coils of the various devices so as to prevent them from operating until some other essential operation has first taken place.

The interlocks used on the magnetic contactors consist essentially of a contact bar or bars attached through insulation to the contactor armature and contact fingers which are attached to the contactor frame through insulation. The electro-pneumatic contactors are equipped with sliding contact type interlocks consisting of insulated segments and fingers which are attached to the contactors.

Throttle Operating Mechanism. An electro-pneumatic mechanism is mounted on each engine to operate its Woodward governor. The mechanisms operate electrically in steps under the control of the throttle on the master controller.

Each mechanism consists of three small air cylinders and pistons actuating a lever attached to the Woodward governor. The governor is held in its idling position against the pressure of its speeder spring. The three pistons move the main lever by means of rollers and a system of interconnecting levers and links so that the lever assumes seven definite progressive positions after leaving the idle position as the air cylinders are energized in different combinations. The cylinders are supplied with air by individual magnet valves. There is also a master valve, called the *EV* magnet valve in the air line to the throttle mechanism. Each successive step of the lever compresses the governor speeder spring and raises its engine regulating speed. The full travel of the end of the lever from idle to full speed is $1\frac{1}{32}$ in.

Reverser for Traction Motor. The purpose of the reversers

is to change the connections to the traction motor fields and thus reverse the direction in which the locomotive will move.

This reverser is of the electro-pneumatic type and is operated by a double cylinder air engine controlled by two *ON* type magnet valves. The reverser is electrically interlocked so that it cannot be operated except with the motor contactors open. Leads from the traction motors are connected to the reverser terminals and the operation of the reverser changes the direction of the flow of current through the fields, thereby reversing the rotation of the motors. Refer to above instructions on the magnet valve for information on the valves used on this reverser.

Series Contactors S1, S21. The series contactors are of the electro-pneumatic type with electrical interlocks. They are used in the motor circuit to connect the motors on each truck in series. They are electrically interlocked with the parallel contactors, so that the parallel contactors cannot operate while the series contactors are closed and vice versa.

Parallel Contactors P1, P2, P21, P22. The parallel contactors are of the electro-pneumatic type, using air pistons to close the contactors against heavy springs. These are electrically interlocked with the series contactors and the generator field contactors and others, so that the series contactors cannot close while the parallel contactors are closed and the generator field contactor cannot close until the proper motor contactors are closed.

Field Shunting Contactors and Interlocks M1, M2, M3, M4. The field shunting contactors and interlocks are of the silver faced contact type. They are used for connecting the motor field shunting resistors in the circuit. They are under the direct control of the voltage control and field shunting transfer relays.

Time Delay Control Relay TDR1, TDR21. This relay is used in the traction motor field shunting circuits. It inserts a one second time delay in operation when going back from field shunting to full field motor connections. Its purpose is to give any possible surges time to die out before the field shunting relay can pick up again. A copper cylinder around the core inside its coils causes a one second delay in the drop out action. This delay inserts resistance in series with the shunt coil of the field shunting relay so that the

latter cannot pick up for one second. This delay in transition in going back from *field shunting* to *full field* connections permits any possible surges to die out before the field shunting relay picks up and establishes the full field motor connections.

Traction Motor Transfer and Field Shunting Control Relay V1, V21. This relay automatically transfers the motors from series to series-parallel and operates the field shunting contactors at the proper times. The relay operates with each successive rise of generator voltage, advancing the motor connections from series, to parallel, to field shunting.

An insulated base supports an inverted **T**-shaped magnetic frame to which a double acting balanced armature is pivoted.

With both coils de-energized the contacts are held in the open position by the armature spring, which forces the lower plunger against its core. The upper (shunt) coil is connected, in series with suitable external resistors, across the main generator armature and thus the current through it is proportional to generator voltage. The lower (series) coil is connected in parallel with the main generator and exciter series field windings and its current is proportional to generator current. The relay will operate at relatively low voltage with no load on the generator. The pick up voltage increases rapidly with increasing generator current. In this manner transition will occur at very nearly the same locomotive speed regardless of the notch on which the throttle is set.

Wheel Slipping Relay WS1, WS21. This relay is provided to measure the difference in voltage between the respective motors of each pair of traction motors when operating in the series connection. In the event either wheel slips, its motor voltage increases, while the voltage on the other motor decreases. This difference in voltage causes the relay to be energized and operate the warning light. It also prevents transfer to parallel motor connections taking place while the slipping lasts.

After parallel connections are established, interlocks on *P2* and *P22* disconnect the relays. The relay works momentarily whenever a power plant transfers from series to parallel so that a brief flash of the indicating lamp will not mean wheel slipping, but will indicate that transfer has taken place on one power plant. A sub-

sequent brief flash shows that another plant has undergone transfer from series to parallel connections.

Engine Starting Contactors with Interlocks GS1, GS2, GS21, GS22. These contactors are of the magnetic type and are used for connecting the starting winding of the generator to the storage battery for starting the engine. They are electrically interlocked with the other control apparatus so that when they are closed, the generator field contactor and other contactors are locked open so that no power current can be applied to the motors until the starting contactors open.

Reverse Current Relay RC1, RC21. The purpose of this relay is to prevent the battery from discharging through the auxiliary generator if the voltage regulator cannot hold the auxiliary generator voltage up to its predetermined setting by reason of the engine speed being too low or other cause. It governs the action of the battery charging contactor *B1, B21,* closing it whenever the auxiliary generator is developing sufficient voltage to charge the battery and opening the contactor whenever the auxiliary generator voltage falls appreciably below the battery voltage, 2 or 3 volts.

The relay has two operating coils, one of which, the shunt coil, is connected in series with a resistor tube across the auxiliary generator; the other, a series coil, is connected so as to carry the total current supplied to the battery circuit. This includes all battery loads as well as the actual battery charging current.

The series coil is connected so as to aid the shunt coil when current is flowing from the generator to the battery and to oppose it when the current reverses. Since the series coil is not connected in the circuit until the battery charging contactor is closed, it has no effect on the pick-up voltage, but it will govern the drop-out voltage.

Battery Charging Contactor with Interlock B1, B21. The battery charging contactor is of the magnetic type and it is used to connect the storage battery to the auxiliary generator for charging purposes. This contactor is directly controlled by the reverse current relay, so that it will not operate until sufficient voltage is flowing to charge the battery against the battery voltage. It also is suitably interlocked with other control equipment so that other

contactors will not operate until the battery charging contactor is closed.

Voltage Control Relay X1, X21. The relay is a dynamic type, voltage regulating device, equipped with a counterweight for smooth operation under rough track conditions. Constant voltage is held on the auxiliary generators over the normal speed and load ranges. Special connections are provided so that the auxiliary generators operate in parallel when both engines are running.

Whenever the auxiliary generator voltage exceeds the calibration value, resistance is cut into the shunt field circuit to restore the voltage to normal. The opposite action takes place upon a decrease in voltage.

Any circulation of current between the two auxiliary generators when operating in parallel, creates voltages of opposite polarity across two halves of a resistor. This changes the regulator coil currents, tending to lower the voltage setting on the auxiliary generator transmitting the circulating current, and to raise the setting on the auxiliary generator receiving the circulating current.

Electrical Indicating Instruments V, BA, 132A, 132B. The locomotive is equipped with a voltmeter in the battery charging circuit and with ammeters in the battery and traction motor circuits.

The instruments operate on the D'Arsonval principle, using a permanent magnet for the field and a coil on the moving element for the armature.

On account of the high current on which ammeters operate, they are provided with external shunts to carry the heavy current.

The ammeters in the main power circuits are calibrated into operating zones and are called *load indicators.* The engineman must be careful to follow the operating instructions regarding the load indicating zones so as not to damage the motors and generators in the main circuits.

The battery meters should be observed periodically to insure proper charge and prevent a run down battery on the road.

The charging current should be between 0 and plus 5 amperes. Immediately after starting up a Diesel engine the charge current will be high (about plus 50) but this will return to normal shortly, as soon as battery voltage is brought back up to normal.

The battery voltmeter should read 75 volts (approx.) when the Diesel engines are running and 64 volts when they are shut down.

D. ELECTRICAL TROUBLES

General. The presence of trouble is usually indicated by complete or partial loss of power, unusual noises, smoke, or the smell of overheated insulation near the damaged apparatus.

Electrical failures should be relatively rare. In such cases it is desirable to know how to replace fuses, and what fuses to remove or what switches to throw to cut out the parts in trouble, and permit operating the locomotive with as much remaining equipment as possible.

Overheated Motors. These will be indicated by smoke or odor of burning insulation coming from below the floor level. A better indication is melted solder from the commutator being thrown on adjacent parts. Determine by inspection which motor is hot. If motor cut-out switches are provided, cut out this motor. If not, shut down the power plant supplying this motor, which will kill two motors.

Flashovers. Occasionally current may jump between brushes on the main motors, generators or exciters. This is evidenced by noise, sometimes a loud pop, sometimes not very loud. Usually the flash goes to ground and trips the ground relay. Inspect the machine which flashed over if it can be found. If any serious damage has occurred (holes burned in commutators or brushholders burned off or touching commutator) it will be necessary to shut down that power plant. Usually damage will be hardly noticeable, and perhaps the machine which flashed over cannot be determined. In this case, reset the ground relay and try operation again. If no further flashovers occur, no action need be taken except to report the occurrence at the end of the run.

Delayed Transition. This would be noticed by the train failing to pick up speed properly. It can be checked by looking at the *S1* and *S21* contactors. If these are closed, the locomotive is operating in *series* instead of parallel. Unless a broken wire or some other repairable failure is readily seen, transition on plant No. 1 may be brought about by pushing *CR1* relay closed with a stick, and or

plant No. 2 by similarly closing *CR21* relay. After pushing them closed, they should remain so until the throttle is closed.

Low Engine Speed. If the Diesel engines fail to reach full speed, low power will be noted. This may be due to valves not operating on the throttle mechanisms located on the side of each engine. This may be checked by pressing the armature button on top of each of the three valves. If on Notch 8, they should all be energized, and if pressing any one increases the engine speed, that valve is at fault. This may be due to dirty contacts in the controller or on the relays in these coil circuits.

Loss of Power on Notch 8. If power decreases when taking Notch 8, something may be open in the speed switch circuits. If it cannot be found readily, the simplest solution is not to go above Notch 7.

Ground Relay Tripping. This will be evidenced by a sudden loss of power, alarm bell, and lighting of ground relay lamp. It means a ground has occurred. It may be harmless or more serious due to a flashover. If there is any reason to suspect a flashover, look for burned or smoked apparatus, and proceed as described under *flashovers*.

If nothing is found, reset the relay and try again *without* opening the ground relay cut-out switch, so the protection will still be available on the second try. Someone should be back in the engine room when this is tried, so that if the relay trips again he can note if any noises or flashes occur.

Restarting should be tried three times, and if the ground relay kicks out each time, that power plant should be shut down or your railroad's instructions followed.

BLOWN FUSES

Most troubles in the control circuits are indicated by the blowing of a fuse. Sometimes fuses open from age and vibration when there really is nothing wrong, and merely need to be replaced. For this reason it is a good idea, if plenty of fuses are available, to replace a blown fuse and try again. If the fuse blows a second time, note what was done by the engineman when the fuse blew, as this may be a clue as to what portion of the circuits is at fault.

Fuse 106. This is a 225 ampere fuse in the main battery circuit, and should scarcely ever blow. If it does, it will kill nearly everything but the lights. Unless some other fuse should also blow, there is not much that can be done unless the cause can be found. Except for the possibility of it blowing simultaneously with some other fuse beyond it, the trouble will be in the heavy wiring between it and the battery.

Fuses 107A, 107B. These fuses handle battery charging current from the auxiliary generators. If one blows, the other generator will still handle the control loads and charging, so it is not particularly necessary on the road to do anything. It may be due to the regulating relay being set for too high a voltage. The fuse should be 200-ampere size.

Fuses 110A or 110B. If one of these fuses blows it will stop the No. 1 power plant, and on some locomotives it will shut down both power plants. If it blows a second time and no remedial trouble can be found, it may be left blown or removed, and reduced operation will still be possible from the other power plant (or power plants, if running two units in multiple).

On some locomotives the fuses numbered 110A and 110B feed all control circuits, and their blowing will kill everything. On these locomotives all switches should be opened, and then start up one piece at a time. If the fuse blows again, the thing being done at the moment will tell what circuit is in trouble. This power plant may then be cut out of service to make it possible to operate the balance of the equipment.

Fuses 111, 111A, 111B, etc. These fuses are all lighting and voltmeter fuses and will not affect the operation of the locomotive. They should be checked if the battery voltmeter does not read or if any lights will not burn.

Fuses 210A or 210B. If one of these blows it will stop the No. 2 power plant, which may be treated like power plant No. 1, as described under fuses 110A or 110B above.

Fuses 310A or 310B. If one of these fuses blows, tractive power will be lost when running single unit, and also when running the multiple unit if one blows on the leading *A* unit. If 310B blows on either unit, engines will stop in the *B* unit. In some cases

opening engine control buttons Engine No. 1 or Engine No. 2 will enable continued operation with the remaining power plants. If operating in multiple unit, operation may be had from good unit by pulling train-line jumpers. If operating in single unit, both power plants are out of service until the trouble can be found and remedied, unless opening one of the engine control buttons permits the other plant to operate.

Fuses 410A or 410B. These fuses feed the compressor and fuel pump contactor operating coil circuits. Since these are the only devices on these fuses, they should rarely blow. If they blow on a single unit locomotive, the unit is out of service until the trouble can be found and remedied. When operating two units in multiple, blowing of fuse 410A on the *A* unit will shut down all engines. In this case, operation may be had from the good unit by pulling the train-line jumpers.

No Headlight. On some locomotives, two sets of headlight resistors are provided, with a three-pole, double-throw selector switch. If the headlight goes out, this switch may be thrown over which will restore the light if a burned out resistor is at fault. More likely the bulb has burned out and must be replaced.

On locomotives with 12-volt headlights, there is an emergency switch to feed the light directly from the battery, if the dynamotor or *MG* set fails. This connection should only be used in emergency, as it causes a bad drain on the battery and will run down a fully charged battery in a few hours to a point where it might endanger its ability to crank an engine.

E. LIST OF ELECTRICAL EQUIPMENT

The following is a list of electrical equipment devices tabulated by power plants, giving symbol by which each is indicated on the electrical connection diagram, the name of the device and its function or circuit.

HEAD END CONTROL SWITCH BS-126-K3

No. 1	No. 2	Jointly	Device	Function or Circuit
		C	(PB) Control	Automatic alarm bells and lights; engine speed and propulsion relays
		GF	(PB) Gen. Fld. Switch	Propulsion relays and contactors
		FP	(PB) Fuel Pump Switch	Fuel pump contactor
		AC	(PB) Switch	Attendant call alarm bells

Device Symbol Used on Power Plant

THROTTLE (CONTROLLER) STAND 17KC46D1

No. 1	No. 2	Jointly	Device	Function or Circuit
			Reverse handle	Controls direction
			Throttle lever	Controls speed
FP No. 1	FP No. 2		(PB) Fuel pump switch	Fuel pump motor—Governor solenoid—Auxiliary generator Field
ST.1	ST.2		(PB) Engine start switch	Cranks engine
Eng. No. 1	Eng. No. 2		(PB) Isolation switch	When open holds engine at idling speed
		17HP9A1	(PB) Sander switch	Energizes sander valves

PUSH BUTTON SWITCHES BS-126-A8

No. 1	No. 2	Jointly	Device	Function or Circuit
		(PB)	Push button switch	Headlight dim
		(PB)	Push button switch	Headlight bright
		(PB)	Push button switch	Gauge and number lights
		(PB)	Push button switch	Classification lights
		(PB)	Push button switch	Defroster
A	A		Load indicator	Shows current flowing in motors
A1	A2		Auxiliary generator	Charges battery and supplies control power
		AVR	Sequence relay	Controls excitation
		B	Battery	Power for control and starting
		BA	Battery ammeter	Shows battery charge and discharge

E. LIST OF ELECTRICAL EQUIPMENT—*Continued*

No. 1	No. 2	Jointly	Device	Function or Circuit
Device Symbol Used on Power Plant				
B1	B21		Battery charging contactor	Connects auxiliary generator to battery
		BVR	Sequence relay	Controls excitation
CR1	CR21		Control relay	Series to parallel transfer
		CR2	Control relay	Cuts in speed switch
		CR3	Control relay	Shuts down engine
		CVR	Sequence relay	Controls excitation
		DVR	Sequence relay	Controls relay CR2
E1	E2		Exciter	Energizes main generator and field circuit
EF1	EF21		Exciter field contactor	Connects exciter shunt field to battery
EV1	EV21		Magnet valve	Controls air to throttle operators
		EVR	Sequence relay	Decreases 6th notch excitation
		FPC	Fuel pump contactor	Energizes fuses 110A and 210A. Feeds all engine control circuits
G1	G2		Main generator	Furnishes power for traction motors
GF1	GF21		Main generator field contactor	Energizes main generator field
GR1	GR21		Ground relay; connects Motors No. 1 and No. 3 to ground	Takes load from main generator upon ground and drops engine back to idle
GS1 GS2	GS21 GS22		Cranking or engine starting contactors	Turns engine over from battery — Pos. Neg.
M1 M2	M3 M4		Field shunting contactors	Weakens traction motor fields for higher locomotive speeds
OPR1	OPR21		Oil pressure relay	Takes load from engine and lights oil signal lights
P1 P2	P21 P22		Propulsion contactors	Connects traction motors in each pair in parallel
RC1	RC21		Reverse current relay	Operates battery charging contactor
-||- No. 1	-||- No. 21		Reverser	Changes motor connections for direction of rotation
S1	S21		Propulsion contactors	Connects traction motors in each pair in series

E. LIST OF ELECTRICAL EQUIPMENT—*Continued*

No. 1 Device Symbol Used on Power Plant	No. 2 Device Symbol Used on Power Plant	Jointly	Device	Function or Circuit	
		S-16	Compressor governor	Maintains air pressure in main reservoir	
		SR	Signal relay	Rings alarm bells	
T1 T2 T3	T21 T22 T23		Magnet valves for throttle operator	Control speed of Diesel engine	
TDR1	TDR21		Time delay relay	Prevents pumping in going from field shunting to parallel	
		V	Voltmeter	Battery voltage	
V1	V21		Transition relay	Controls transitions	
WS1	WS21		Wheel slip relay	Lights lamp when wheels slip when in series	
X1	X21		Voltage regulating relay	Controls auxiliary generator voltage	
1 2	3 4		Traction motors	Transfer engine power to wheels and rail	
		100	Switch—400-amp.	Disconnects battery	
102A	102B		Switch—60 amp.	Disconnects ground relay	
104A	104B		Speed switch	Controls engine speed on 8th notch	
		105	Shunt—200-amp.	Battery ammeter	
		106	Fuse—225-amp.	Battery	Pos.
107A	107B		Fuse—200-amp.	Auxiliary generator	Pos.
		108A	Fuse—60-amp.	External battery charging	Pos.
		108B	Fuse—60-amp.	External battery charging	Neg.
110A			Control fuse —30-amp.	No. 1 Engine Control Positive	
110B			Control fuse —30-amp.	No. 1 Engine Control Negative	
		111A	Fuse—30-amp.	Headlight and Interior Lighting	Positive
		111B	Fuse—30-amp.	Headlight and Interior Lighting	Negative
		111C	Fuse—30-amp.	Headlight and Interior Lighting	Positive
		111D	Fuse—30-amp.	Headlight and Interior Lighting	Negative
113A	113B		Fuse—15-amp.	Aux. Gen. Field	
		115A	Fuse—30-amp.	Boiler water Pump motor	Positive
		115B	Fuse—30-amp.	Boiler water Pump motor	Negative
116A 116B	116C 116D		Capacitor	Connected across speed switch contacts—prevents arcing	
118A	118B		Governor solenoid	Admits oil to governor	

E. LIST OF ELECTRICAL EQUIPMENT—*Continued*

No. 1	No. 2	Jointly	Device	Function or Circuit
Device Symbol Used on Power Plant				
123A	123B		25-lb. oil pressure switch	Takes load from main generator—drops engine back to idle
124A	124B		20-lb. oil pressure switch	Shuts down engine
		127	Transformer	125/75-volt a-c for lights
		128	Receptacle	For attaching outside source of a-c for lights
		130	Switch DPST	Connects lights to battery or to transformer
138	138		Shunt for load indicator	In negative motor lead
		139	Magnet valves	Operates Sanders
	210A		Fuse—30-amp.	No. 2 Engine Control Positive
	210B		Fuse—30-amp.	No. 2 Engine Control Negative
		310A	Fuse—30-amp.	Voltmeter and multiple unit — Positive Positive
		310B	Fuse—30-amp.	Control devices — Negative
		410A	Fuse—30-amp.	Fuel pump, Contactor and compressors, Control circuits
		410B	Fuse—30-amp.	Negative
		9013	Pneumatic control Deadman switch	Cuts off power to traction motors—holds engine down to idling speed

F. CONTACTOR AND RELAY SEQUENCES

The contactor sequences is the order in which the various power switches and relays are closed under different conditions as shown on the connection diagram contactor sequence table. They can be observed through the mesh screen doors. In this way it is possible to be sure that all the proper connections are being made. The change or transfer from one set of connections to another is called *transition.*

Series to Parallel Transition. The *transition* from *series* to *parallel* is brought about by the transfer and field shunting relay, *V1* and *V21*. This relay has coils measuring generator volts and amperes, and controls the transition.

Parallel to Field Shunting Transition. When the locomotive speed reaches the *transition* point for field shunting operation, the transfer and field shunting relay *V* again picks up, and this time connects resistors which shunt some of the current out of the motor fields. This results as before in a lowering of generator voltage

SEQUENCE TABLE																								
			CONTACTORS									RELAYS										VALVES		
CONDITION		CONTROLLER NOTCH	S1, S21	P1, P21	P2, P22	M1,M2,M3,M4	GS1, GS2	GS21, GS22	EF1, EF21	FPC	GF1, GF21	CR1, CR21	CR2	CR3	V1, V21	WS1, WS21	AVR	BVR	CVR	DVR	EVR	T1, T21	T2, T22	T3, T23
START ENGINE No. 1		IDLE					●			●														
START ENGINE No. 2		IDLE						●		●														
IDLING		IDLE								●														
SERIES		1	●						●	●	●													
		2	●						●	●	●						●					●		
		3	●						●	●	●								●				●	
		4	●						●	●	●						●		●			●	●	
		5	●						●	●	●							●		●				●
		6	●						●	●	●						●	●	●	●	●		●	●
		7	●						●	●	●							●	●				●	●
		8	●						●	●	●		●				●	●	●			●	●	●
TRANSITION	T1	8	●						●	●	●		●		●		●	●	●			●	●	●
	T2	8	●						●	●	●	●	●		●		●	●	●			●	●	●
	T3	8	●						●	●		●	●		●		●	●	●			●	●	●
	T4	8	●	●					●	●		●	●				●	●	●			●	●	●
	T5	8		●					●	●		●	●			●	●	●	●			●	●	●
	T6	8		●	●				●	●		●	●			●	●	●	●			●	●	●
PARALLEL		8		●	●				●	●	●	●	●				●	●	●			●	●	●
FIELD SHUNT		8		●	●	●			●	●	●	●	●		●		●	●	●			●	●	●
ENGINE STOP		STOP								●				●						●				

Fig. 1. Contactor and Relay Sequence Table

and an increase in generator amperes, permitting still further acceleration of the locomotive at full horsepower.

Field Shunting to Parallel and Parallel to Series Transition. If a grade is encountered which slows down the train, resulting in increased current and falling voltage, the relay may drop out again. This will unshunt the fields, decrease the generator current, and increase the voltage. This returns the motors from the *reduced field* (field shunting) to the normal *parallel* connection. No amount of reduction in locomotive speed will automatically return the motors to the *series* connection. If the grade is heavy enough to overload

the motors in parallel motor connection, the throttle must then be shut off and opened again. The motors will then come back in *series* as on any start, and remain there until the grade eases and the locomotive accelerates when the *series* to *parallel* transition will again take place.

Motor Cut-Outs. To cut out both motors in one plant, isolate that engine. On locomotives so equipped, one motor may be cut out of either power plant by operating its respective cutout switch. With one motor cut out, changes are made in the excitation circuit so that the corresponding generator output is cut approximately in half to compensate for the loss of one motor. This condition holds whether the good plant's motors are in series or parallel connection. Reduced field (field shunting) on the single motor is obtained whenever the good plant's motors are shunted. In this way the single motor at all times carries very close to its proper share of the load.

Contactor and Relay Sequences. The sequence of operation of the various contactors, relays, and magnet valves for each throttle notch and transition point is spotted in the above table. (Fig. 1.)

This sequence is based on transfer from motors in series to motors in parallel occurring on Notch 8 and simultaneously in both plants.

This transfer may occur on one plant a little before the other, and it may occur on any notch. If it occurs prior to Notch 8, sequence of motor contactors is the same, but the sequence of *AVR*, *BVR*, *CVR*, *DVR*, *EVR*, relays and **T**-valves is completed afterward,

Not shown are the *B1* and *B21* contactors which are controlled by *RC1* and *RC21* relays. They are normally closed at all times after engines are running.

The circuit relations between the various components of the locomotive electrical equipment are shown in a series of eight schematic diagrams, Figs. 4 to 11 inclusive.

The connections between the various components of the locomotive electrical equipment are shown on a typical locomotive connection diagram.

Figs. 2 and 3 show the arrangement of the fuses, switches, contactors, relays, and reversers.

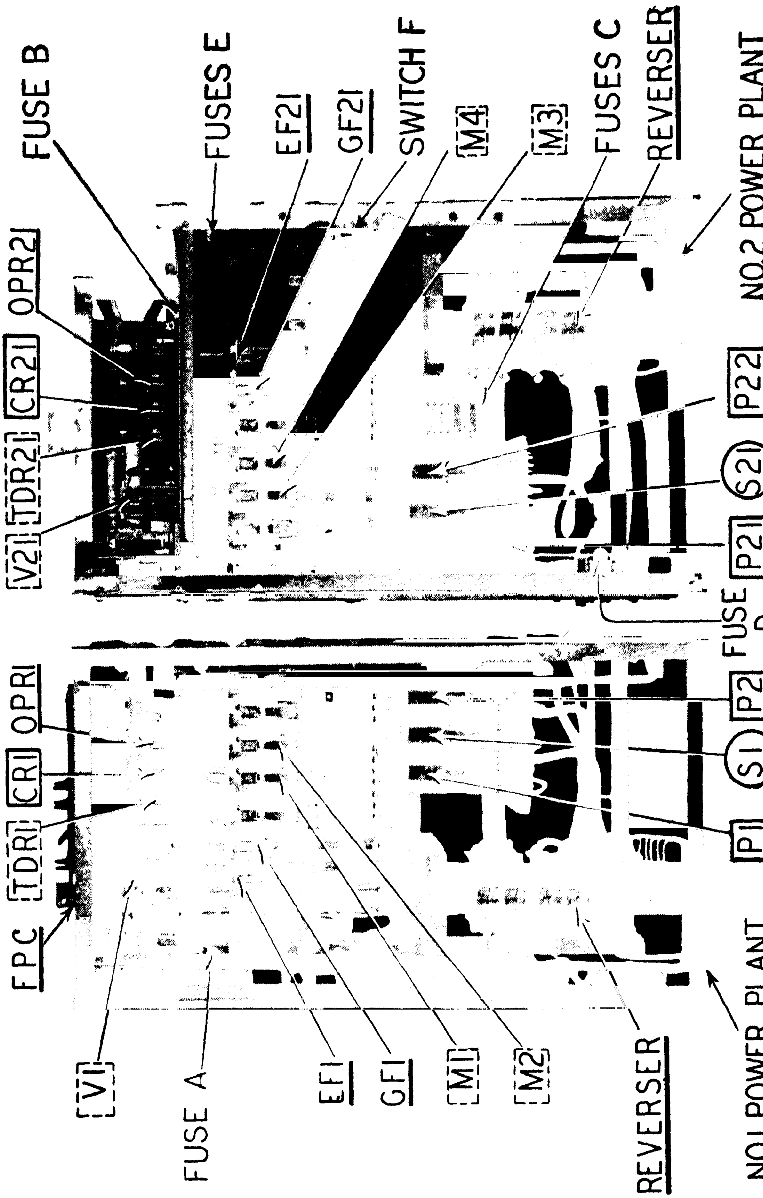


Fig. 2. Contactor and Relay Cabinet

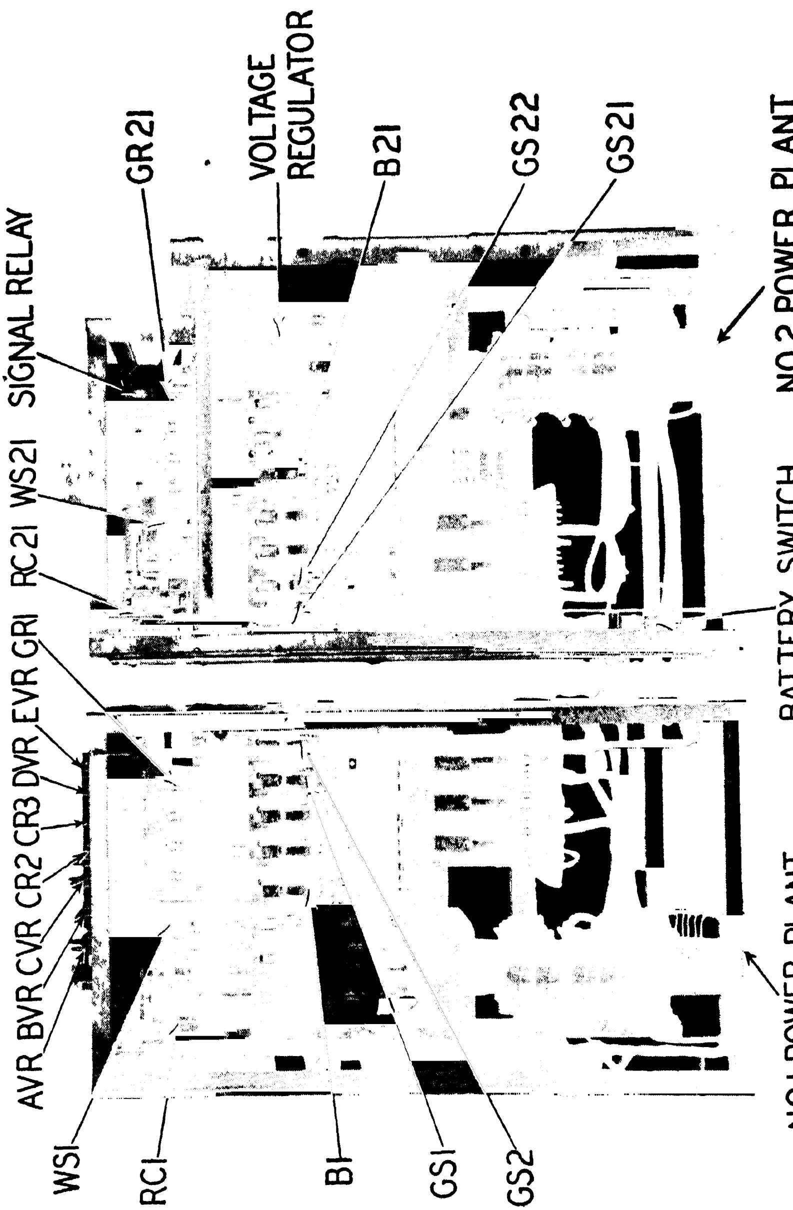


Fig. 3. Contactor and Relay Cabinet

Contactors and Relays. The more important contactors and relays are shown in Fig. 2. Observe these contactors occasionally while on the run with the engines running.

1. Contactors, *GF1, EF1, FPC, OPR1, OPR21, EF21, GF21,* with *symbols underlined* should be closed when the throttle is in any notch, *1* to *8*. The reversers must be in either forward or reverse position.

2. In *series* the contactors *S1, S21,* with *encircled symbols* must also be closed.

3. In *parallel* the contactors *P1, P2, CR1, CR21, P21, P22,* with *symbols in solid box* must be closed. During transition from series to parallel *V1* and *V21* will close momentarily. *GF1* and *GF21* will drop open momentarily.

4. In *motor field shunting or reduced field* connections the contactors *M1, M2, M3, M4,* and relays *V1, TDR1, V21, TDR21,* with *symbols in broken box* must be closed and also those with *symbols in solid box P1, P2, CR1, CR21, P21, P22.*

5. The remaining contactors and relay positions not indicated above are shown in Fig. 3.

Fuses. The fuses shown at the various positions are as follows;—

(A) 107 A—Auxiliary generator—No. 1 engine—200 Amps.

(B) 107 B—Auxiliary generator—No. 2 engine—200 Amps. This fuse cannot be seen well in the photograph. It is partly obscured by the angle irons.

(C) The two bottom fuses at this position are 100 ampere fuses for the steam generator. The top two fuses shown are external battery charging fuses when used.

(D) 106—Main battery fuse—225 Amps.

(E) Reading from front to back, these fuses are as follows:

30 amp.—110 A—Positive control
30 amp.—110 B—Negative control
30 amp.—111 A—Lamp circuit
30 amp.—111 B—Lamp circuit
30 amp.—111 C—Lamp circuit
30 amp.—111 D—Lamp circuit
30 amp.—113A—Auxiliary generator field (when used)
30 amp.—113 B—Auxiliary generator field (when used)

10 amp.—back-up light
10 amp.—marker light
10 amp.—vestibule light
10 amp.—contactor compartment lights.

(F) Double throw switch No. 101 for lighting circuits. (Throw up for lighting during locomotive operation; throw down for power from external source.)

The contactors and relays marked in Fig. 3 are those which were not marked in Fig. 2. They function as follows:

Relays. The following relays will lose for the various throttle positions:

Notch 2—*AVR*
Notch 3—*CVR*
Notch 4—*AVR, CVR*
Notch 5—*BVR, DVR*
Notch 6—*AVR, BVR, CVR, DVR, EVR*
Notch 7—*BVR, CVR*
Notch 8—*AVR, BVR, CVR, CR2*

Relays *AVR, BVR, CVR, DVR,* and *EVR,* control the magnet valves on the operating mechanisms at the engine governors and also control exciter field relay. Relay *CR2* cuts in the speed switches when the throttle is in Notch 8.

ENGINE START—*GS1, GS21, GS2, GS22* closed, all others open.

ENGINES IDLING—*RC1, RC21, B1, B21, FPC, OPR1, OPR21* closed, all others open.

ENGINE STOP—*CR3* and *DVR* close, all others open.

RC1 AND *RC21* control *B1* and *B21.* They should be closed normally for battery charging all the time the engines are running.

GR1 AND *GR21* are ground protective relays. If one should latch closed its power plant will be cut out.

WS1 AND *WS2* operate the wheel slip light to indicate wheel slippage.

G. SIMPLIFIED SCHEMATIC DIAGRAMS

Eight simplified schematic diagrams together with a complete locomotive connection diagram (omitting duplicate circuits for No. 2 power unit) are shown on the following pages.

While these diagrams are typical for all ALCO 2000 Hp. Road locomotives now in service, it is understood that some circuit connections may differ on particular locomotives, depending on requirements.

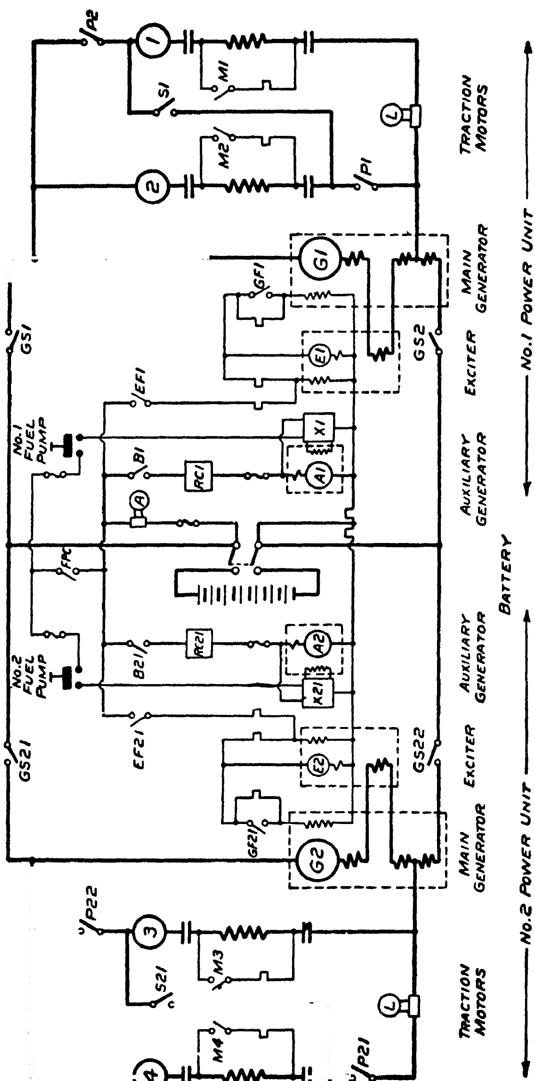
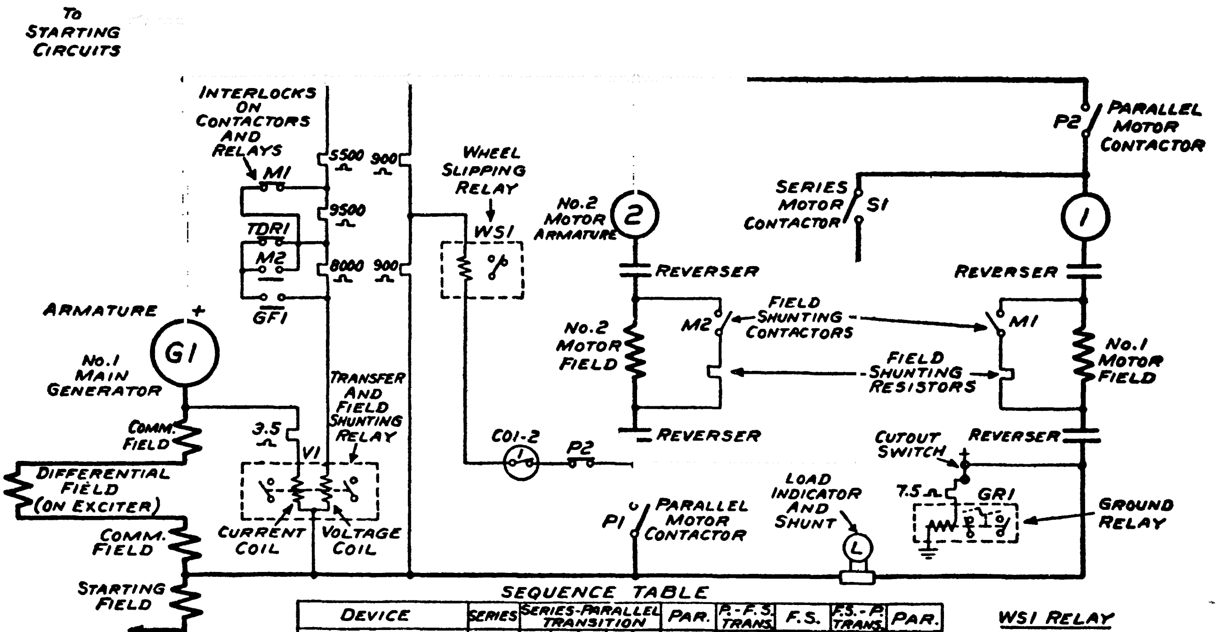


Fig. 4. The Elementary Power Circuits with Principal Connections Between Motors, Generators, Exciters, Auxiliary Generators and Battery



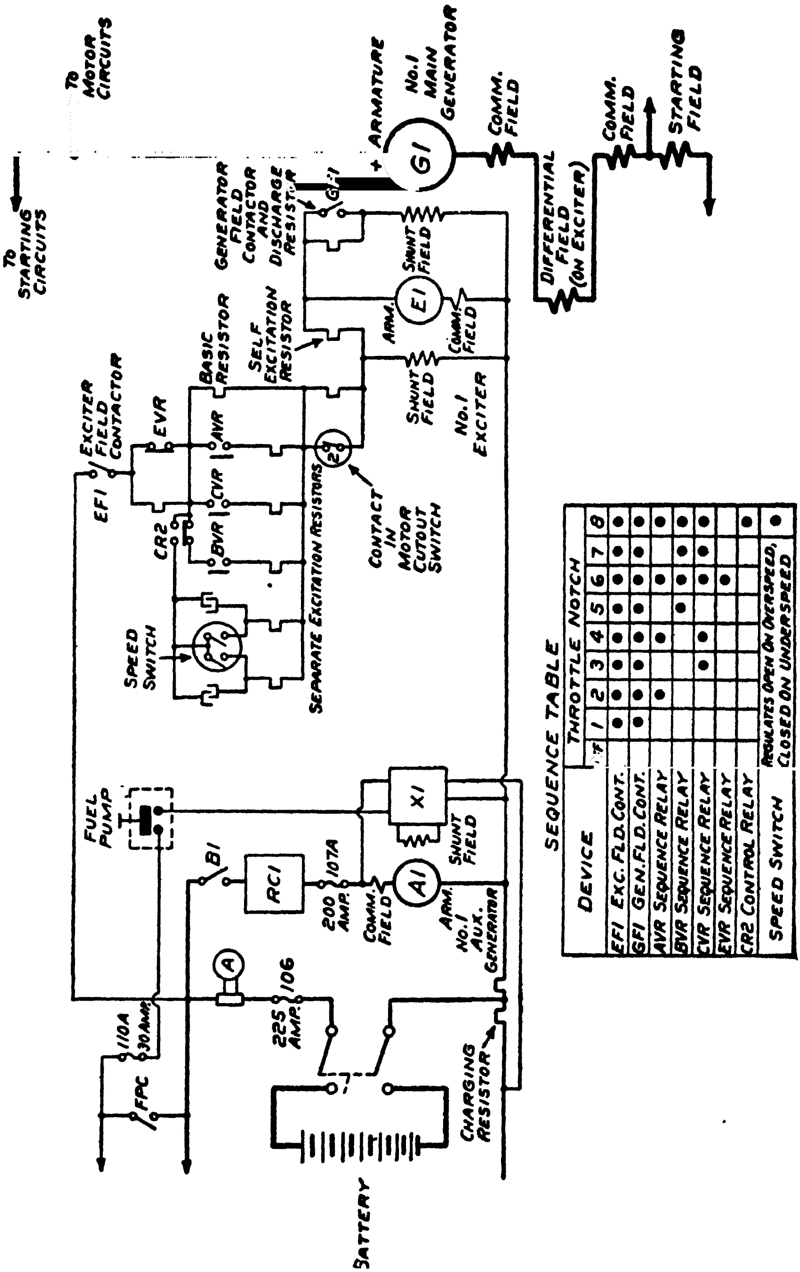
SEQUENCE TABLE

DEVICE	SERIES	SERIES-PARALLEL TRANSITION					PAR.	P.-F.S. TRANS.	F.S.	F.S.-P. TRANS.		PAR.
V1 TRANSFER RELAY		●	●					●	●			
TDR TIME DELAY RELAY									●	●	●	
GF1 GEN. FIELD CONT.	●	●					●	●	●	●	●	●
S1 SERIES CONT.	●	●	●	●								
P1 PARALLEL CONT.				●	●	●	●	●	●	●	●	●
P2 PARALLEL CONT.						●	●	●	●	●	●	●
M1 F. SHUNT CONT.									●	●		
M2 F. SHUNT CONT.									●	●		

V1 RELAY
- INITIATES TRANSITIONS FORWARD FROM SERIES TO PARALLEL, AND INTO AND OUT OF FIELD SHUNTING (IN PARALLEL) AT PROPER GENERATOR VOLTS AND AMPERES.

WS1 RELAY
- EFFECTIVE IN SERIES ONLY.
- OPERATES MOMENTARILY DURING S-P TRANSITION.
- CUTOUT ENTIRELY BY CO1-2 MOTOR CUTOUT SWITCH CONTACT 1 WHEN EITHER MOTOR 1 OR 2 IS CUTOUT.

Fig. 5. A Typical Traction Power Circuit with Connections for the Associated Operating and Protective Relays



SEQUENCE TABLE

DEVICE	THROTTLE NOTCH								
	OFF	1	2	3	4	5	6	7	8
EF1 EXC. FLD. CONT.		●	●	●	●	●	●	●	●
GF1 GEN. FLD. CONT.		●	●	●	●	●	●	●	●
AVR SEQUENCE RELAY			●		●		●		●
BVR SEQUENCE RELAY						●	●	●	●
CVR SEQUENCE RELAY				●	●		●	●	●
EVR SEQUENCE RELAY							●		
CR2 CONTROL RELAY									●
SPEED SWITCH	REGULATES OPEN ON OVERSPEED, CLOSED ON UNDERSPEED								●

Fig. 6. Typical Traction Excitation Circuits

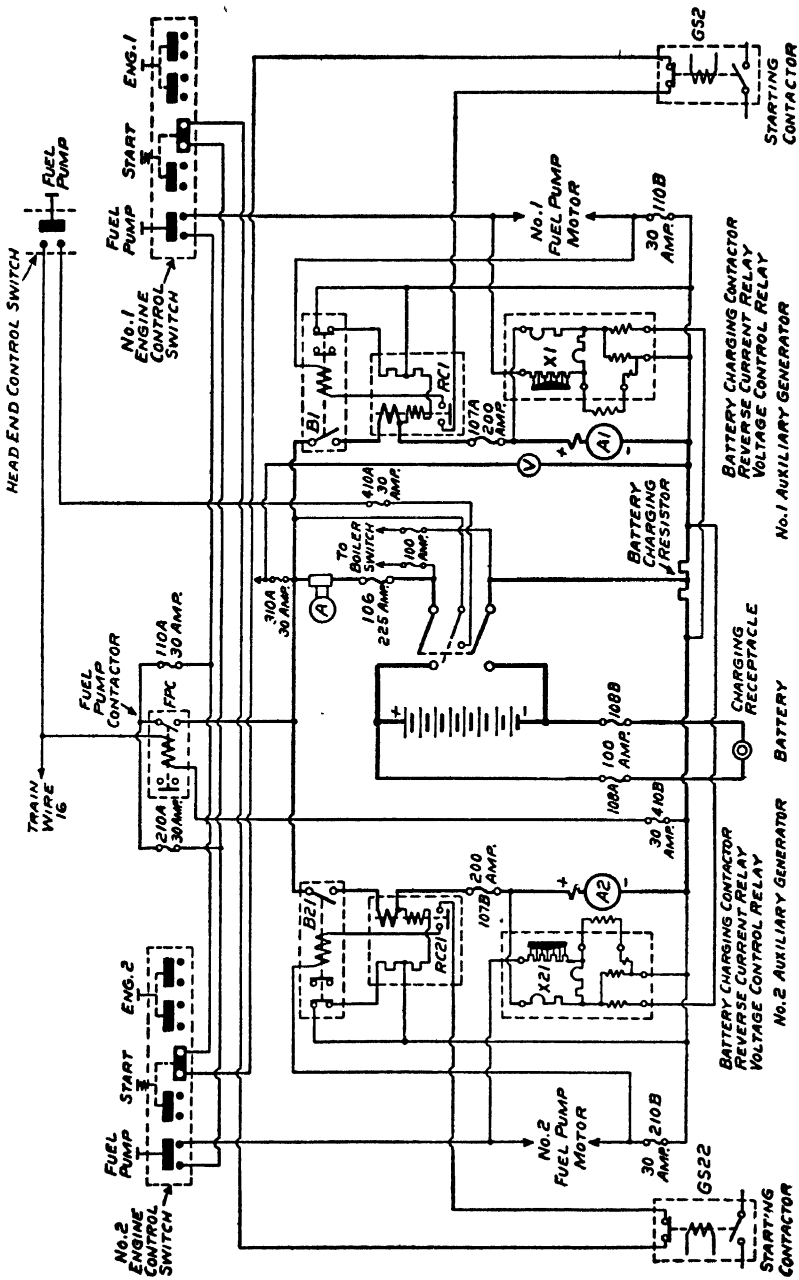


Fig. 7. Typical Battery Charging Circuits

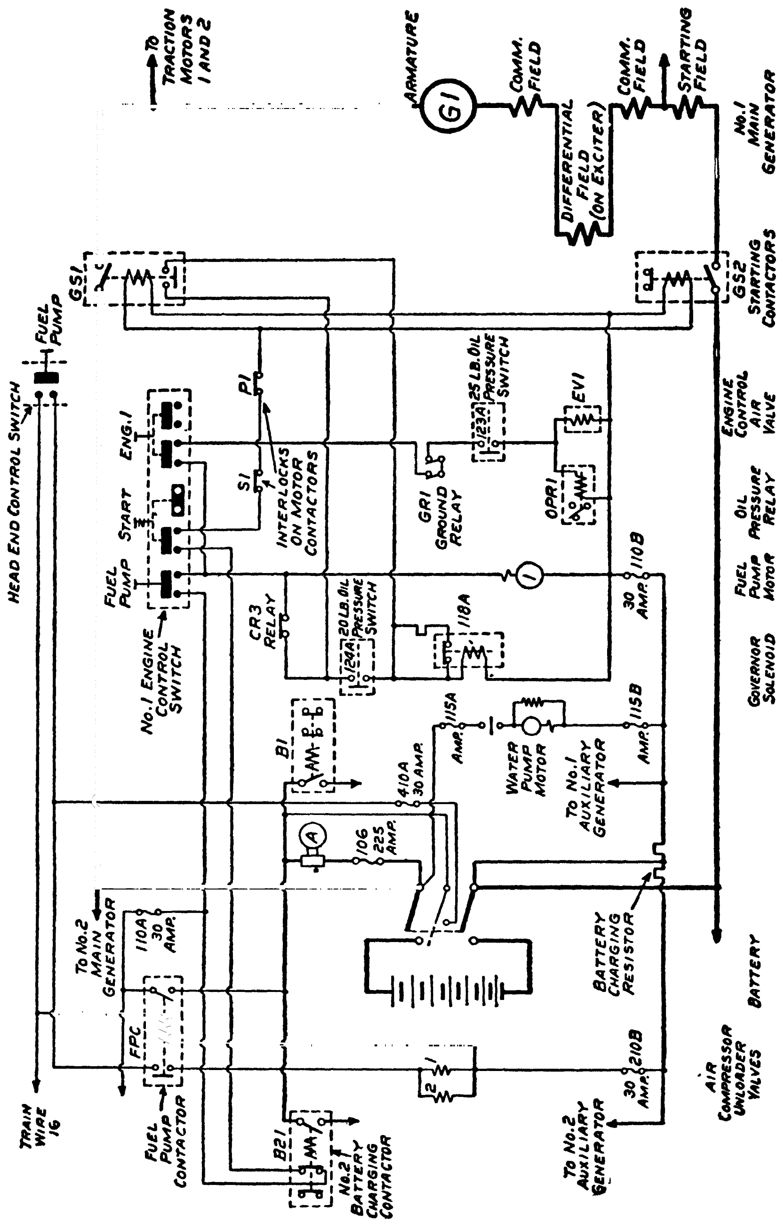


Fig. 8. Typical Engine Starting and Engine Control Circuits

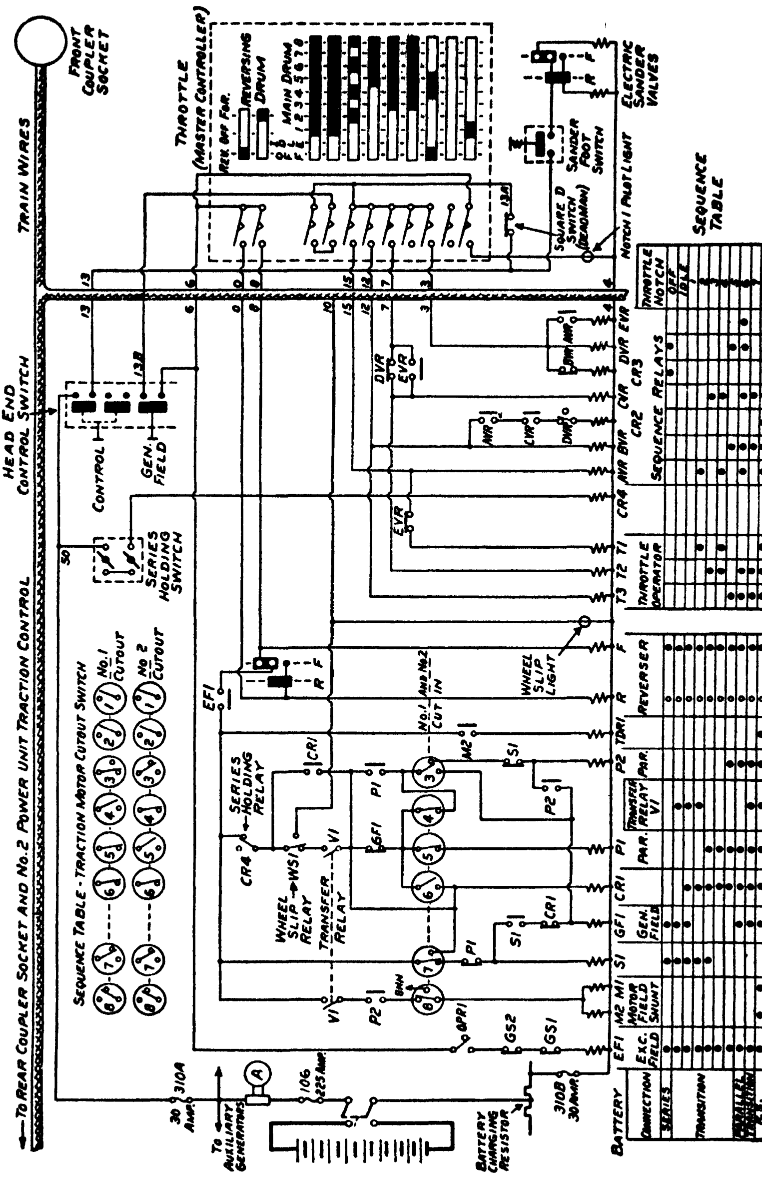
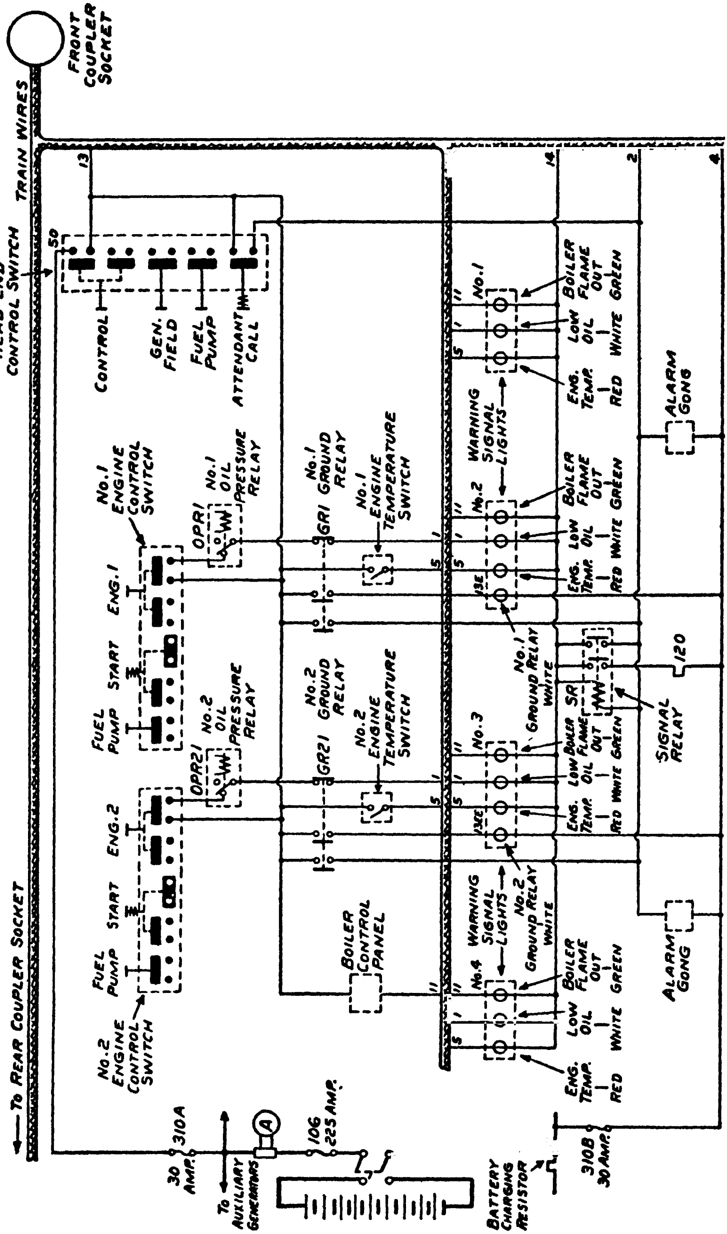


Fig. 9. Typical Traction Control Circuits



NOTE - QUANTITY OF SIGNAL LIGHT STATIONS, ORDER AND COLOR OF LIGHTS, TO SUIT REQUIREMENTS. SUITABLE RESISTORS CONNECTED IN SERIES WITH EACH LIGHT WHERE 32 OR 64 VOLT BULBS ARE USED.

Fig. 10. Typical Alarm and Signal Circuits

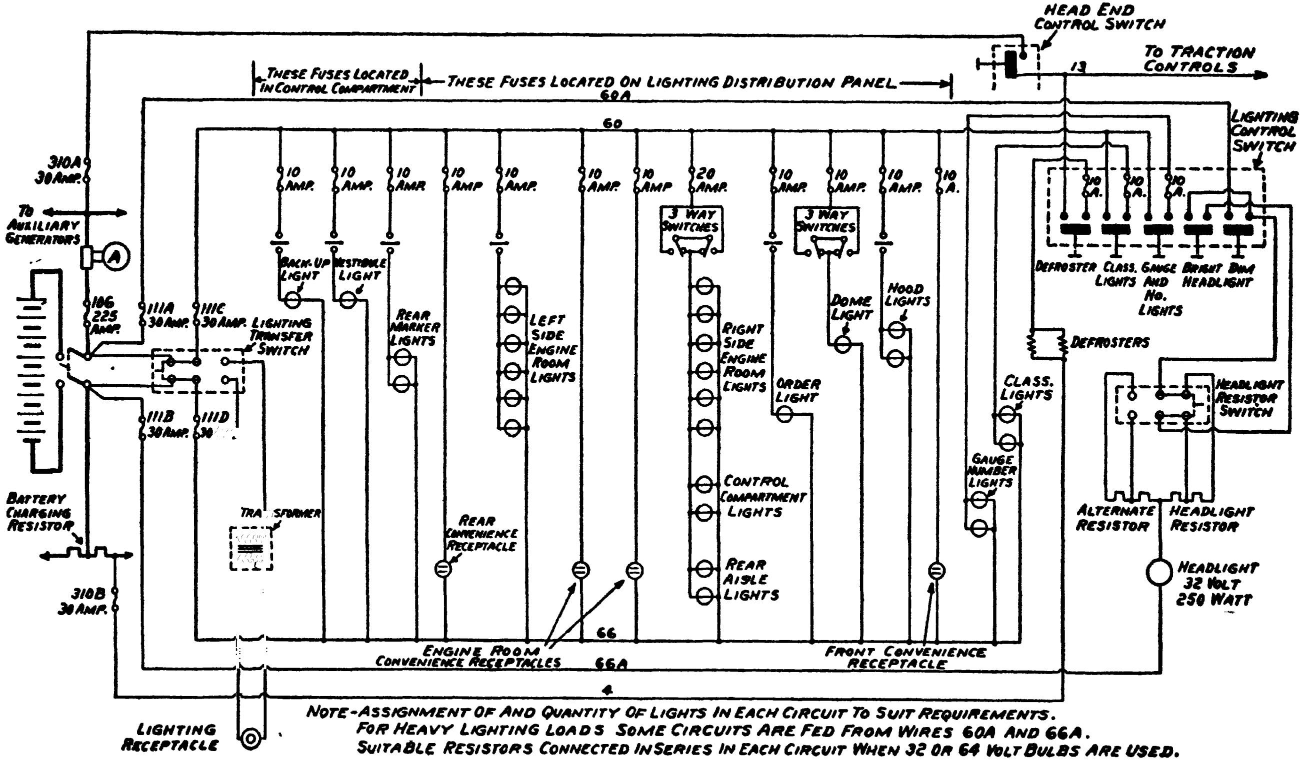
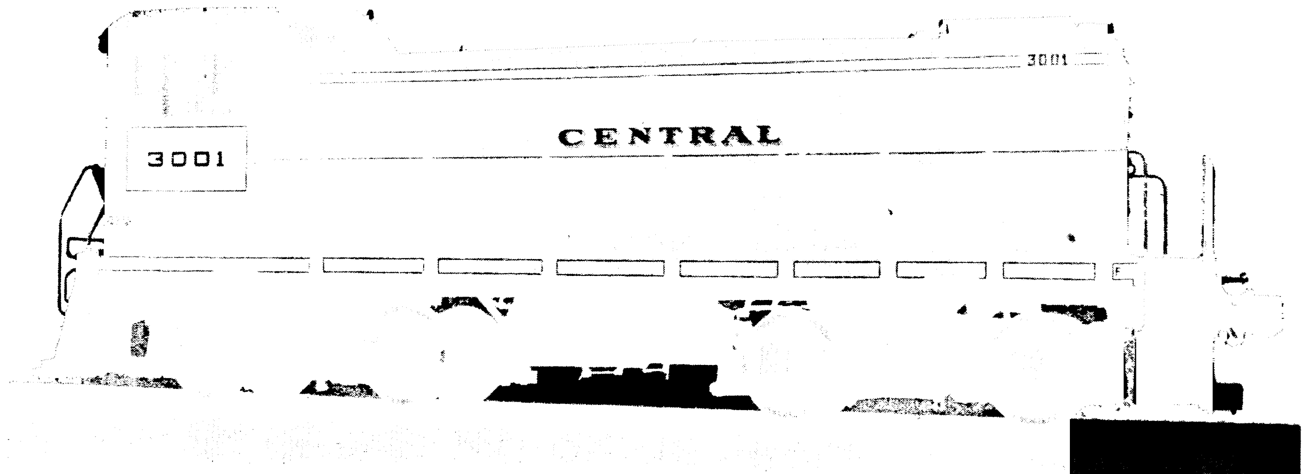


Fig. 11. Typical Lighting Circuits



660 Brake Horsepower Diesel Locomotive
Courtesy of American Locomotive Company

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